NEW

MILITARY COMMERCIAL SPACECRAFT

HOW IT WORKS BOOK OF

AIRCRAFT

AIRCRAFT ON THE FRONT LINE

THE ICONIC APACHE HELICOPTER

EXPLORING THE SOLAR SYSTEM

STUNNING AERIAL DISPLAYS

UNMANNED AERIAL VEHICLES

FLYING AN F-35

FIGHTING FOR AIR-SUPERIORITY

FIGHTER JETS OF THE FUTURE

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TAKE AN ADRENALINE-FUELLED RIDE INTO THE SKY AND BEYOND!

Welcome to

HOW IT WORKS BOOK OF AIRCRAFT

The history of human aviation spans over a hundred years, from the first manned flight of the Wright Flyer in 1903, which flew a groundbreaking 260 metres, to the futuristic spacecraft of today that shuttle astronauts and payloads to the International Space Station. Today's aircraft are constantly evolving and being upgraded; would the Wright brothers even recognise a Eurofighter Typhoon as a descendant of their Flyer? In this new edition of How It Works Book of Aircraft, we will bring to life a plethora of modern flying machines. Find out what it takes to become a pilot for the Red Arrows and how the Supermarine Spitfire became such a successful aircraft in the Military section. Discover how commercial airliners are becoming more and more efficient and what the next evolution of Concorde may look like in the Commercial section. In the Spacecraft section we transport you to the outer reaches of space to search for life on distant planets and investigate how we may soon send humans to Mars with the SpaceShipTwo. Enjoy the book!

HOW IT WORKS
BOOK OF
AIRCRAFT

Imagine Publishing Ltd
Richmond House
33 Richmond Hill
Bournemouth
Dorset BH2 6EZ
☎ +44 (0) 1202 586200
Website: www.imagine-publishing.co.uk
Twitter: @Books_Imagine
Facebook: www.facebook.com/ImagineBookazines

Publishing Director
Aaron Asadi

Head of Design
Ross Andrews

Editor in Chief
Jon White

Production Editor
Sanne de Boer

Senior Art Editor
Greg Whitaker

Designer
Phil Martin

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CONTENTS

Iconic aircraft

008 The world's most iconic aircraft

022 Sky giants

Military aircraft

032 Aerobatic displays

042 100 years of fighter planes

050 On board the Warthog

052 Supermarine Spitfire

054 Lancaster Bomber

056 Sea Harrier

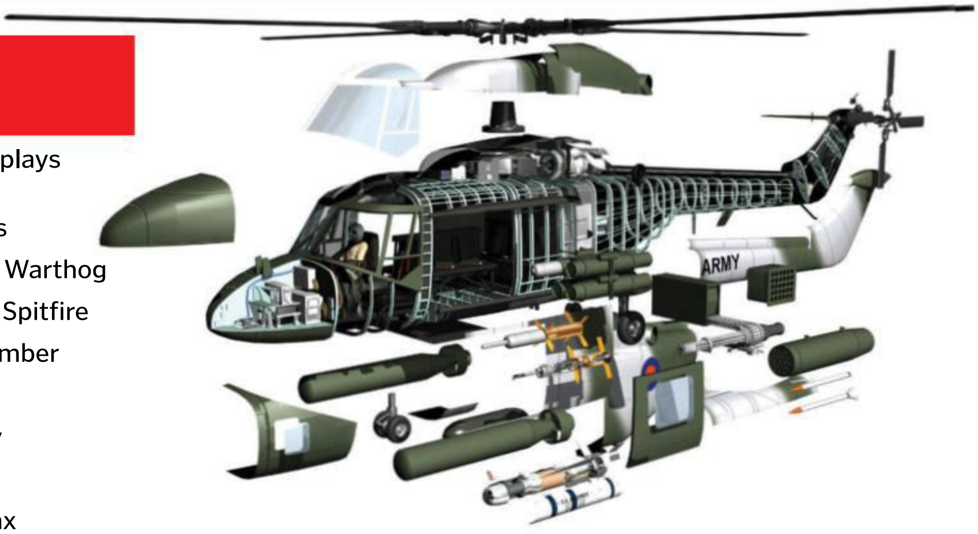
058 Inside a Huey

060 Sea Vixen

062 Westland Lynx

064 Strategic bombers

068 F-35 and future fighters



062 The record-breaking helicopter

126 On board the SpaceShipTwo

On board the Warthog **050**

Aerobatic displays **032**

042

100 years of fighter planes

090

The largest passenger jet

Commercial aircraft

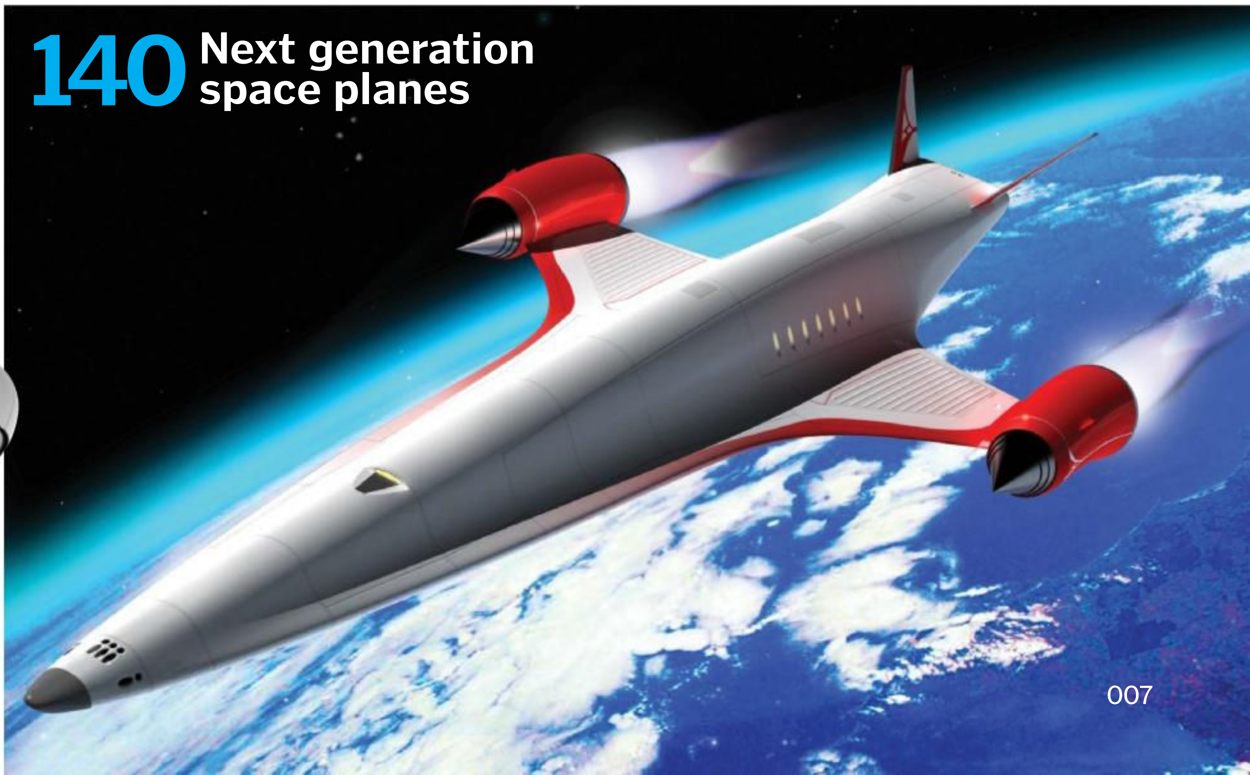
076 Commercial drones
084 How to build a plane
088 The luxury of the Lineage 100 jet
090 World's largest passenger jet
092 The new Concorde
096 Solar-powered aircraft
098 Hot air balloons
100 Inside a cargo plane
102 Boeing 787 Dreamliner
106 Gliders
107 Inside a blimp
107 The Perlan Project
108 Inside Air Force One
110 How to fly a helicopter
111 The AirBoard
112 Next-gen airships

Spacecraft

118 Exploring the outer solar system
122 The evolution of space travel
124 The Orion spacecraft
126 On board the SpaceShipTwo
128 Voyager spacecraft
130 The MESSENGER probe
132 Big Space Balloon
134 Space Shuttle payload bay
136 ATV spacecraft
138 Solar-powered spacecraft
140 Next-generation space planes

140

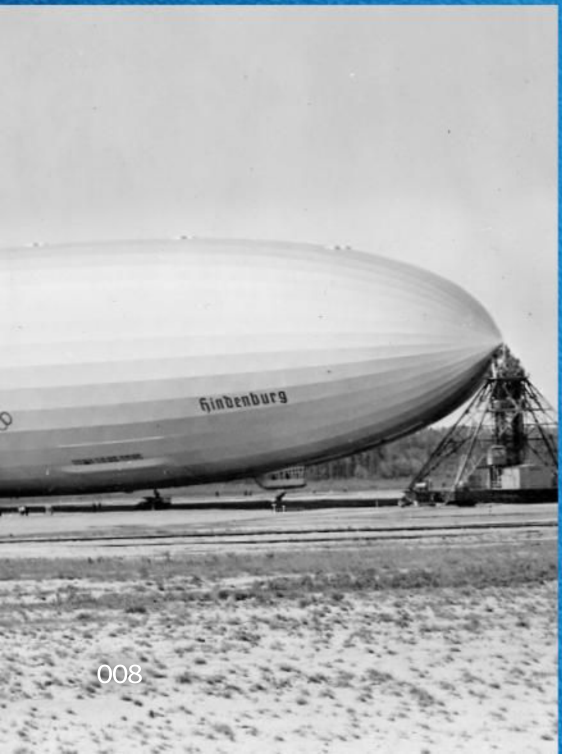
Next generation space planes



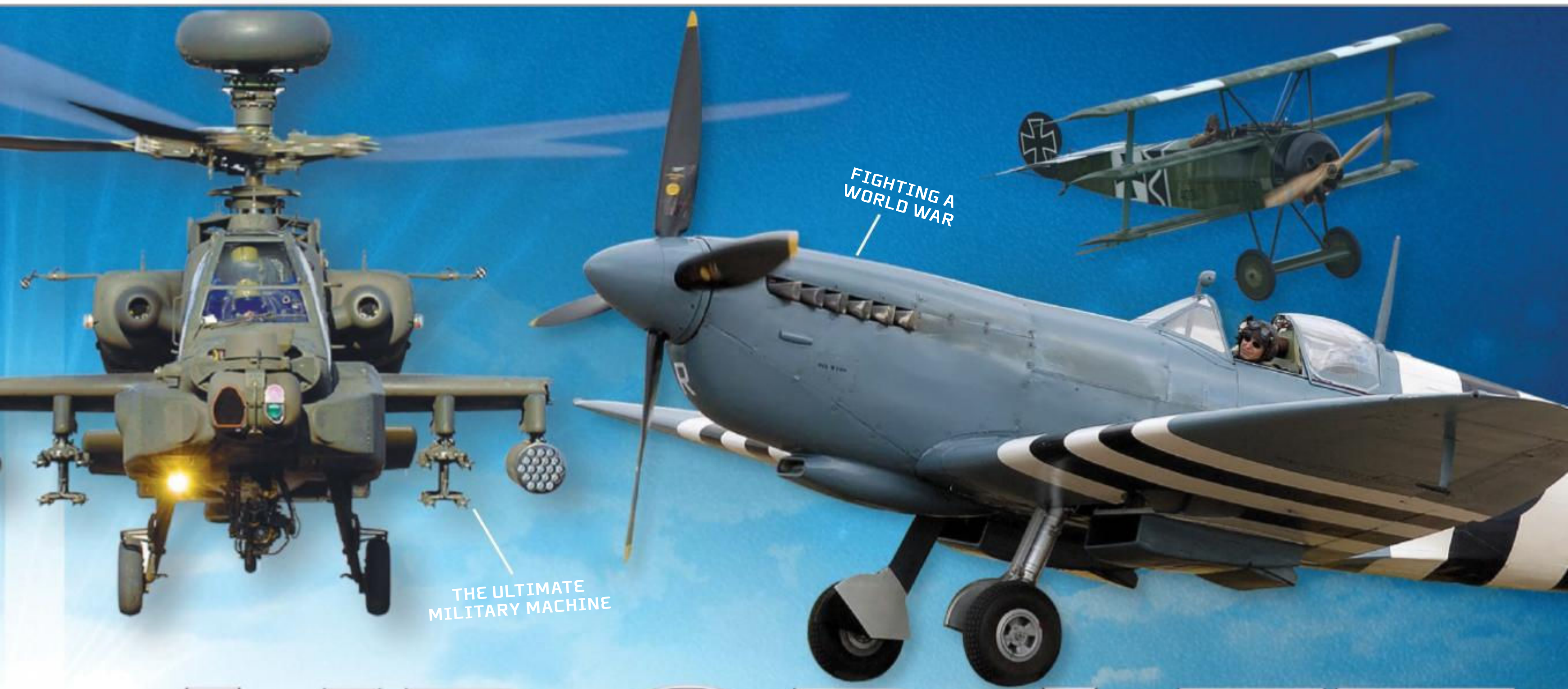
THE WORLD'S MOST ICONIC

BREAKING THE SOUND BARRIER
FLYING AROUND THE WORLD
GOING SUPERSONIC
BELL Aircraft X-1A
BRITISH AIRWAYS

From the early days of aviation all the way through to the modern


Hindenburg

DID YOU KNOW? *The Wright brothers' father, a church minister, was adamant human flight could not be achieved*


FIGHTING A WORLD WAR
THE ULTIMATE MILITARY MACHINE

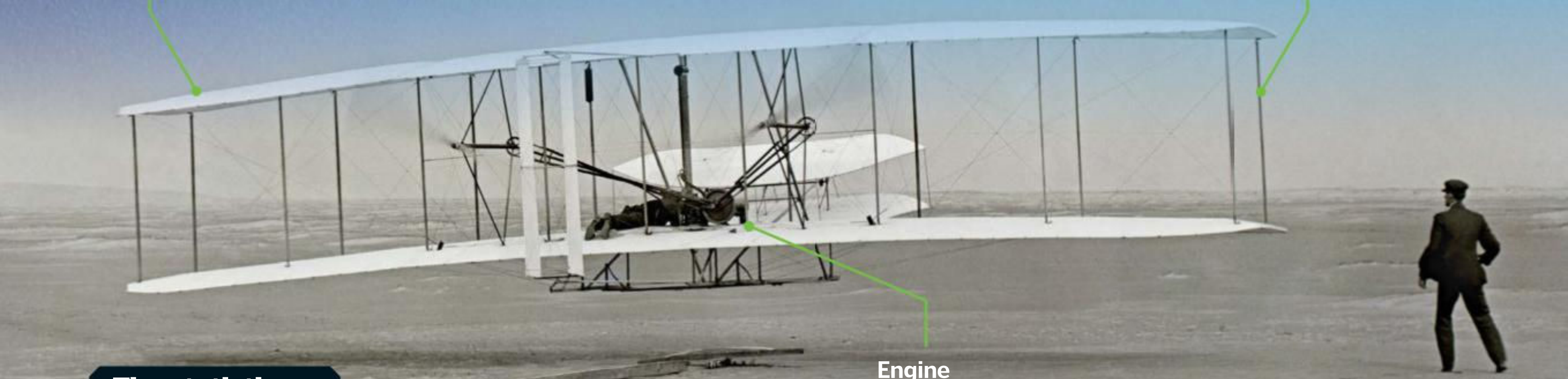
AIRCRAFT

day, iconic aircraft of all shapes and sizes have taken to the skies

Wright Flyer

The iconic aircraft that was created by the most famous of sibling partnerships

Orville and Wilbur Wright were dedicated to their task of developing powered flight. Meticulously tested, the Wright Flyer was constructed in Dayton, Ohio but failed to take off on the first tests carried out on 14 December 1903. It eventually managed to get airborne a few days later on 17 December and achieved a best of 260 metres (852 feet) as Wilbur and Orville took turns to pilot their invention. The aircraft was launched from a short monorail track by two modified bicycle wheel hubs. The engine was very basic and worked using a hand lever that could only open and close the fuel line rather than throttle. Prior to the Flyer, the brothers created various gliders from 1900 to 1903 that were tested without great success. Eventually, they found the perfect formula as it became the first heavier than air machine to get airborne. Designed in a biplane structure, the Wright Flyer had an unfortunate untimely demise when it was wrecked four days after its maiden flight by a huge gust of wind. The design was first housed in the British Science Museum before moving to the Smithsonian National Air and Space Museum in the USA after Orville's death in 1948.



Construction
The aircraft was created out of spruce and ash, which were chosen for their strong yet lightweight properties. Muslin fabric was covered over the wood.

Wing warping
When developing their projects, the brothers designed a system of gears and pivoting shafts that could angle the aircraft in the desired direction.

Engine
The Flyer's power system produced 12 horsepower and was an inline piston engine created by local mechanic, Charlie Taylor.

The statistics...

Wright Flyer

Launch date: 17 December 1903

Length: 6.4m (21.1ft)

Weight: 274.4kg (605lb)

Wingspan: 12.2m (40.3ft)

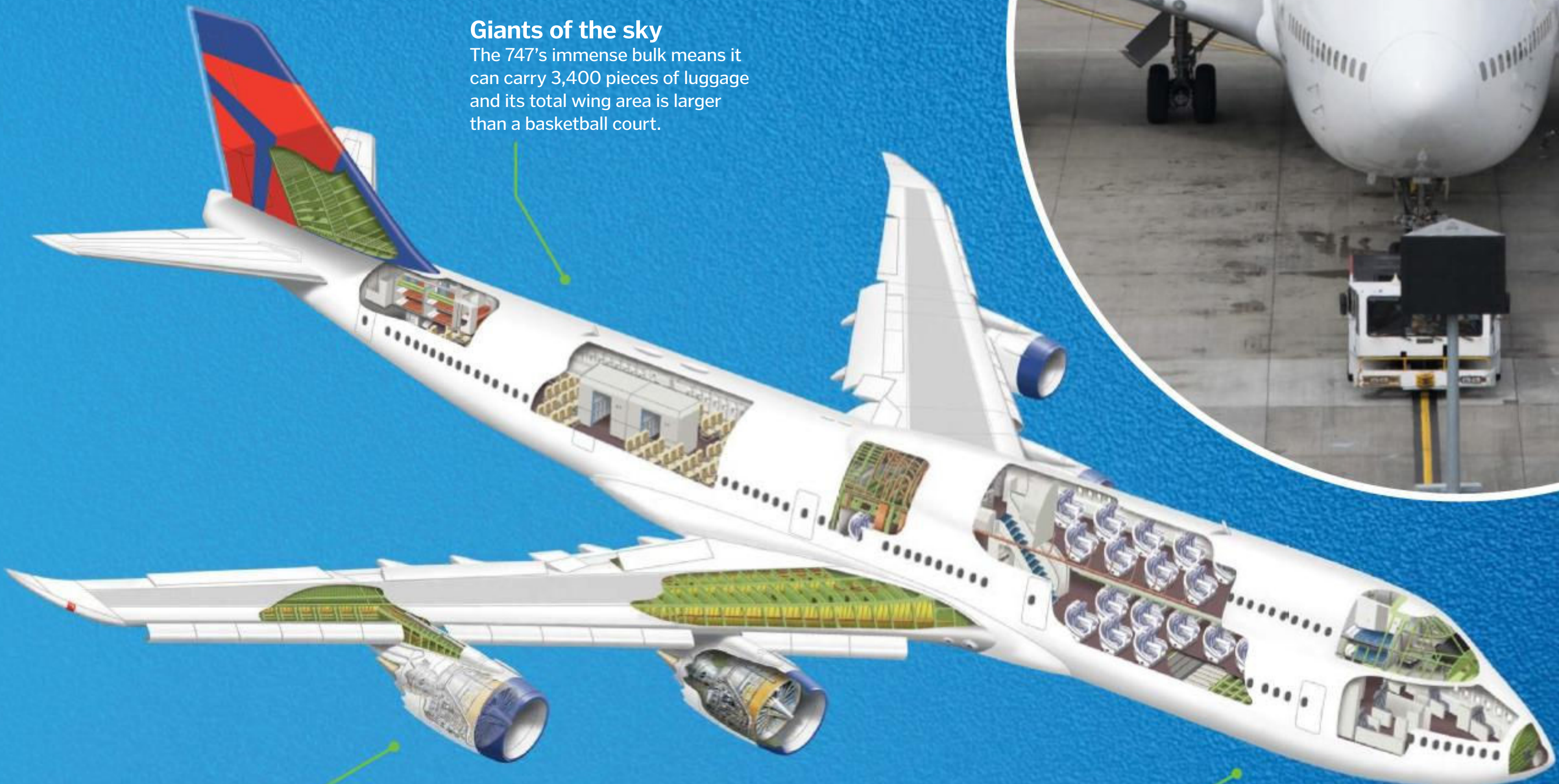
Max speed: Minimal

Max altitude: Minimal

DID YOU KNOW? *The 747 was created by a team of 50,000 people including mechanics, engineers and secretaries*

Boeing 747

A behemoth of the skies, the size and sheer scale of the 747 is now legendary



Giants of the sky
The 747's immense bulk means it can carry 3,400 pieces of luggage and its total wing area is larger than a basketball court.

Engine
In addition to the technology found inside the cockpit, the 747 utilises high-bypass turbofans that make it powerful, fuel efficient and quiet.

Modern technology
As well as being a huge machine, the 747 also contains state of the art technology such as a GPS system that weighs less than a laptop.

In the 1960s, aviation companies had a problem. With the popularity of aviation soaring for business, recreation and industry, the supply of aircraft was struggling to meet demand. But Boeing had a solution up its sleeve; the biggest civilian airplane ever built, the 747. Built in less than 16 months by a group of workers known as 'the Incredibles', the design came in three variations – passenger, cargo and passenger/freighter – and was first flown in 1968. By 1970, this new breed of jumbo jet had fitted seamlessly into the world's air traffic and silenced critics. Since its inception, the 747s have appeared in a variety of models. The 747-400 was first flown in 1988 and is a combination of the earlier freight and passenger models. It is the bestselling model.

Statistics calculated in 2005 reveal that 1,365 747s have been delivered internationally to over 80 different customers. Incredibly, it has flown over 3.5 billion passengers. In recent years, new jumbo jets such as the Airbus may have beaten the 747's size, but it remains an icon of the skies and proof for the first time that gigantic airlines were possible.

The statistics…

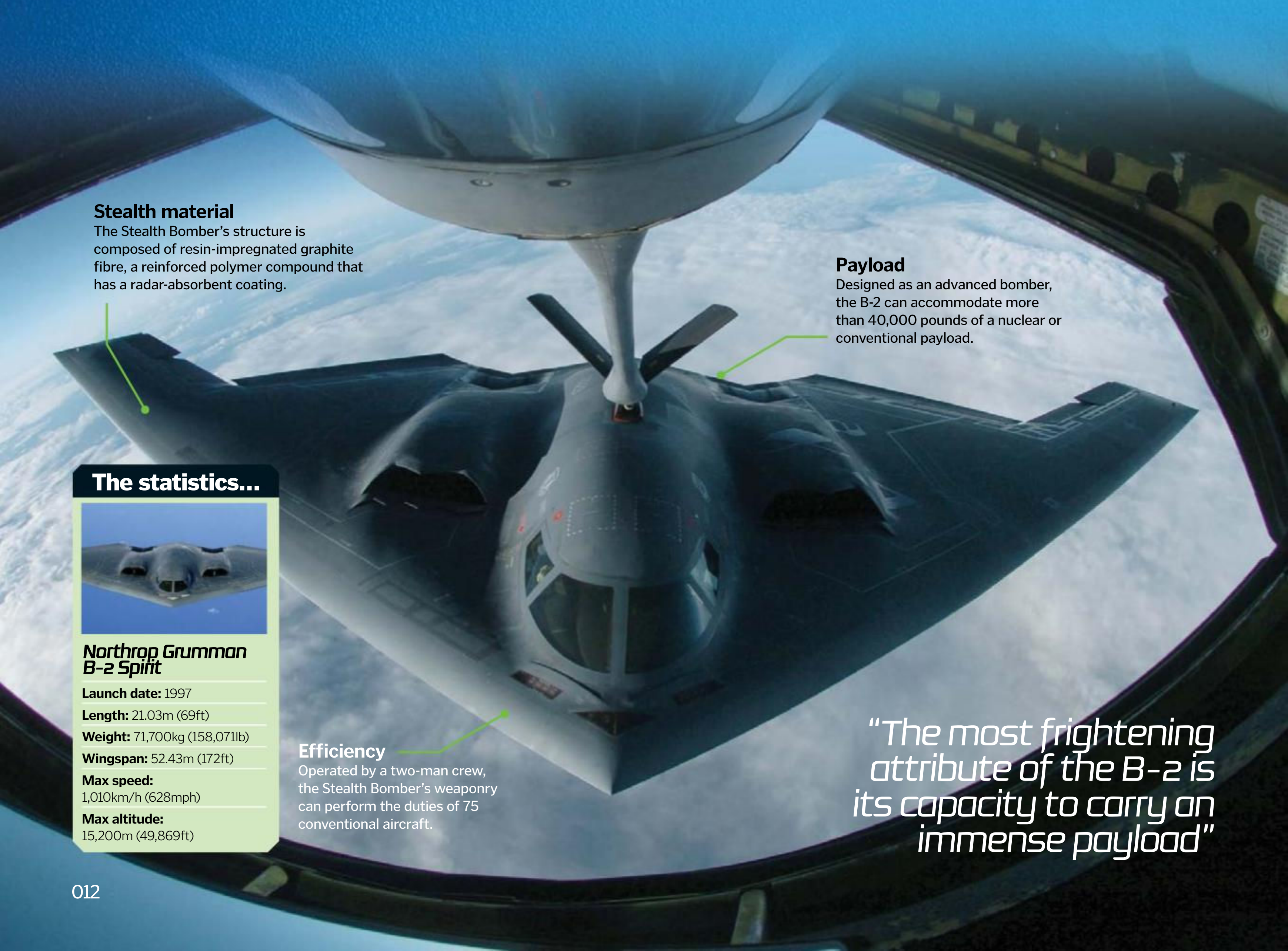
Boeing 747-400

Launch date: 1988
Length: 70.9 metres (231 feet)
Weight: 180,985kg (399lb)
Wingspan: 64.4m (211.5ft)
Max speed: 988km/h (614mph)
Max altitude: 13,449km (8,357mi)
Years in service: 1988-present

Stealth Bomber

Virtually invisible to radar, the Stealth Bomber is a scientific vision turned reality

Commonly known as the Stealth Bomber, the Northrop Grumman B-2 Spirit is a ground-breaking piece of aviation. The design was a giant leap forward in aviation technology and was first flown on 17 July 1989 before joining the US Air Force's operational fleet in 1993. Four 19,000 pound thrust F118-GE engines allow the B-2 to cruise at high subsonic speeds and was, at its peak, the largest military programme at Boeing with 10,000 people employed on the project. The engine is so state of the art that it uses a temperature control system to minimise the aircraft's thermal signature. A strategic, long-range heavy bomber, it only achieved full operational capacity in 2003, ten years after its introduction into the fleet. Twenty-one B-2s are now in operation and are located at the Whiteman Air Force Base in Missouri but are often transported around by a portable hangar system. The most frightening attribute of the B-2 is its capacity to carry an immense payload. Its armament includes many types of nuclear weaponry, Mark 84 bombs, cruise missiles and a rotary rocket launcher to name but a few. A key member of the USA's long range strike arsenal, it can fly in any weather condition and is a force to be reckoned with, especially as it is being constantly updated and improved by the US Air Force.



Stealth material
The Stealth Bomber's structure is composed of resin-impregnated graphite fibre, a reinforced polymer compound that has a radar-absorbent coating.

Payload
Designed as an advanced bomber, the B-2 can accommodate more than 40,000 pounds of a nuclear or conventional payload.

Efficiency
Operated by a two-man crew, the Stealth Bomber's weaponry can perform the duties of 75 conventional aircraft.

The statistics...

Northrop Grumman B-2 Spirit

Launch date: 1997
Length: 21.03m (69ft)
Weight: 71,700kg (158,071lb)
Wingspan: 52.43m (172ft)
Max speed: 1,010km/h (628mph)
Max altitude: 15,200m (49,869ft)

> *"The most frightening attribute of the B-2 is its capacity to carry an immense payload"*

DID YOU KNOW? *Pilots would have to undertake a six-month training programme to be qualified to fly Concorde*

Concorde

The world's only ever-supersonic passenger aircraft is an incredible example of aviation engineering and technology

In 1971 the skies of Britain were dominated by the sound of sonic booms. These were the results of a futuristic Anglo-French project known as Concorde. After 5,000 hours worth of testing (making it the most tested aircraft of all time), it was ready. Seating 100 people, Concorde represented the next step in commercial travel. It was so fast that it still holds the record for the shortest transatlantic crossing, a scintillating 2 hours 52 minutes and 59 seconds. The aircraft accomplished this by utilising 'reheat' technology, which injects extra fuel at takeoff. This innovative technology helped the Concorde fly around the globe in 1992, on the 500th anniversary of Christopher Columbus' journey. It managed to complete the journey in just under 33 hours.

The Concorde's final flight was on 24 October 2003, when it was discontinued after a series of faults that ended in disaster in 2000 when it crashed, killing 113 people. The Concorde made a total of 50,000 flights for 2.5 million passengers and despite its retirement, is still held in high regard as an icon of aviation and there are still calls to bring it back the world's only ever supersonic passenger airline back into service.

The statistics...

Concorde

Launch date: 1976

Length: 62.1m (203ft)

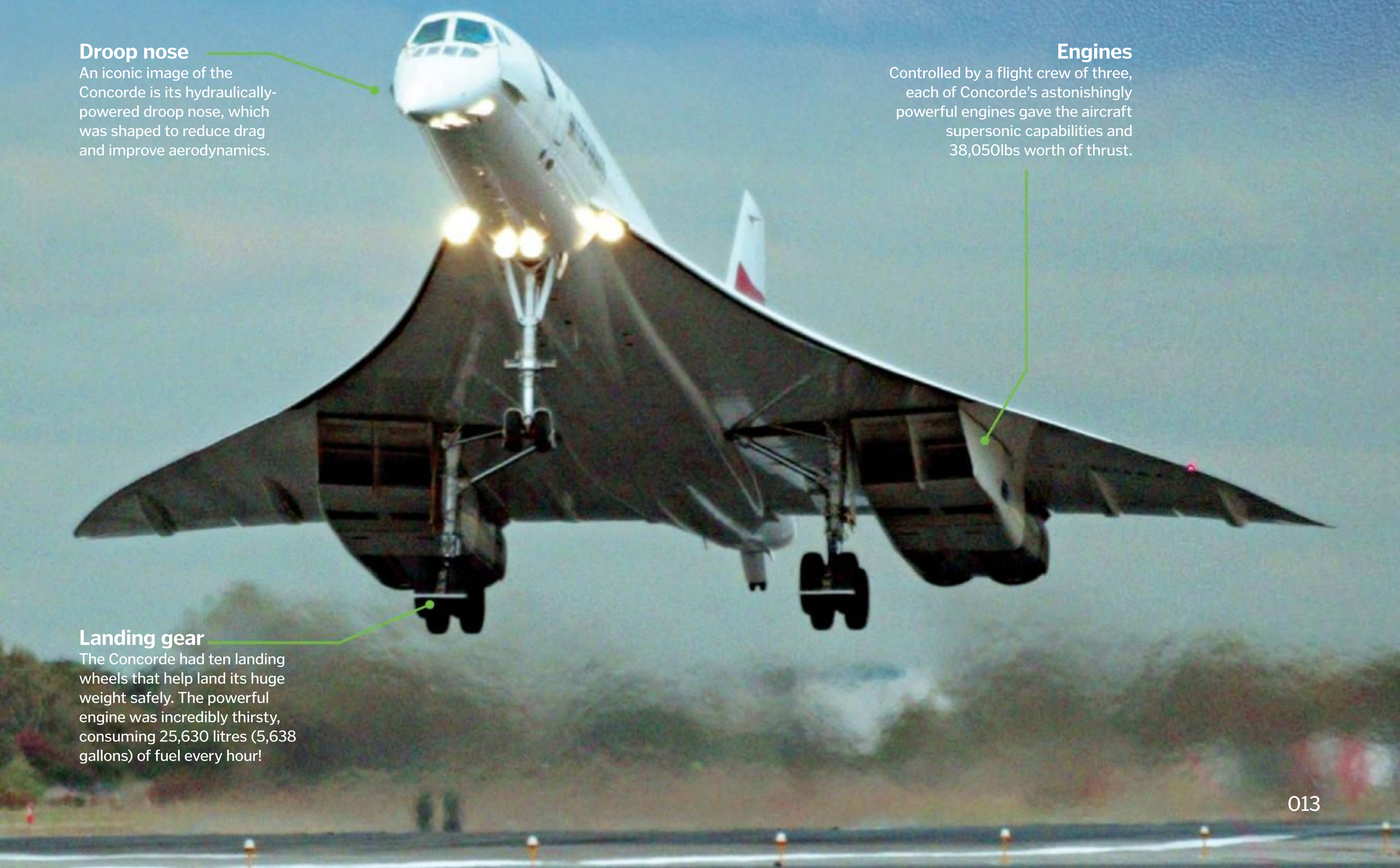
Weight: 10.6 tons (23,400lb)

Wingspan: 25.5m (83.8ft)

Max speed: 2,172km/h (1,349mph)

Max altitude: 18,288m (60,000ft)

Years in service: 27



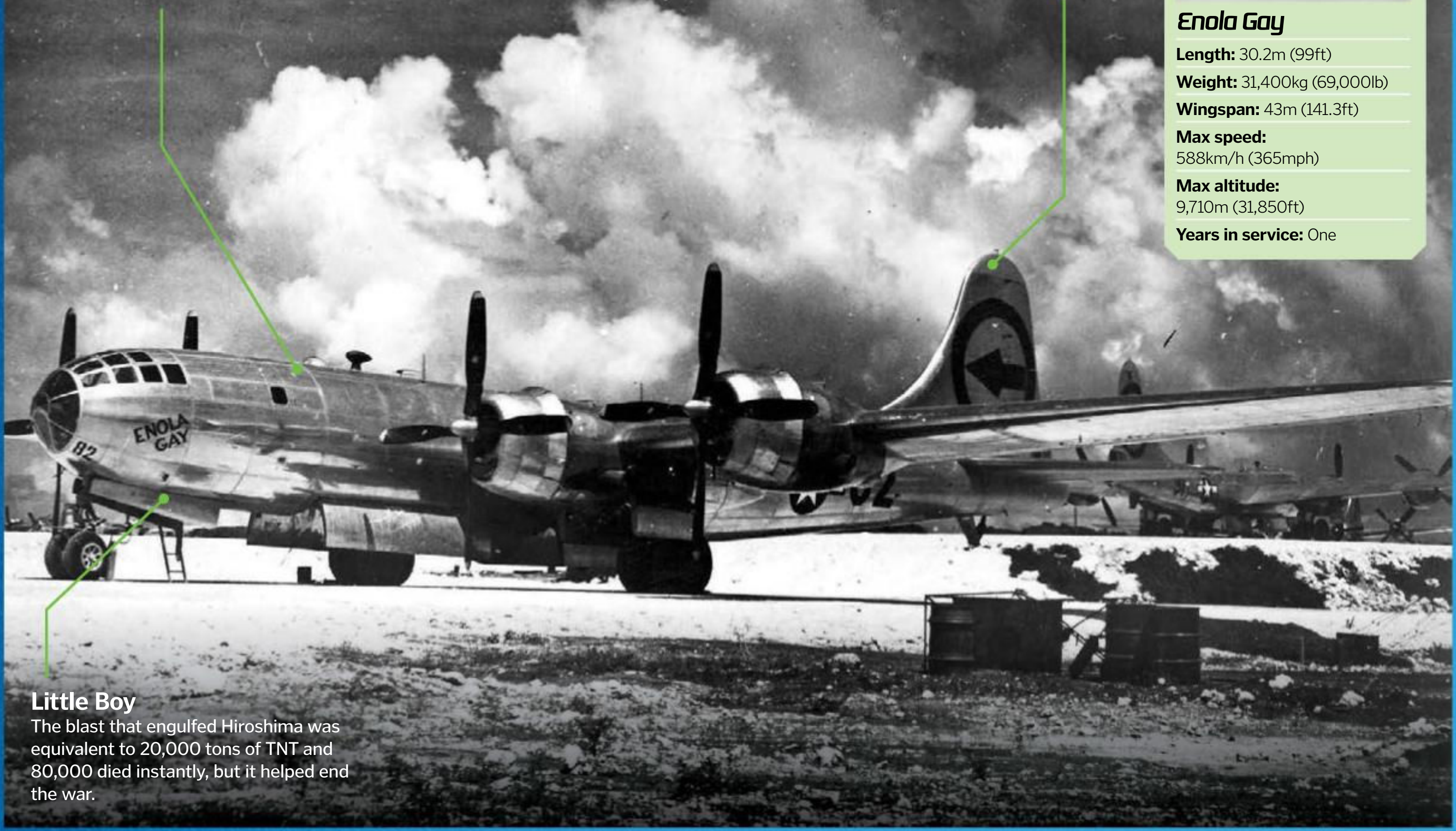
Droop nose
An iconic image of the Concorde is its hydraulically-powered droop nose, which was shaped to reduce drag and improve aerodynamics.

Engines
Controlled by a flight crew of three, each of Concorde's astonishingly powerful engines gave the aircraft supersonic capabilities and 38,050lbs worth of thrust.

Landing gear
The Concorde had ten landing wheels that help land its huge weight safely. The powerful engine was incredibly thirsty, consuming 25,630 litres (5,638 gallons) of fuel every hour!

The Enola Gay

A plane entirely famous for its atomic payload, the Enola Gay dropped one of the most destructive bombs in human history

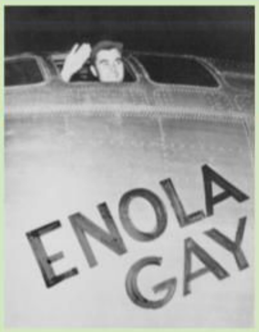


Boeing built
Enola Gay was a type of Boeing B-29 Superfortress and its long range and ability to carry a huge atomic payload made it ideal for the Hiroshima mission.

Production line
Up to 4,000 B-29s were made on a rush basis in what was a huge manufacturing programme with hundreds of thousands of workers.

Little Boy
The blast that engulfed Hiroshima was equivalent to 20,000 tons of TNT and 80,000 died instantly, but it helped end the war.

The statistics…



Enola Gay

Length: 30.2m (99ft)

Weight: 31,400kg (69,000lb)

Wingspan: 43m (141.3ft)

Max speed: 588km/h (365mph)

Max altitude: 9,710m (31,850ft)

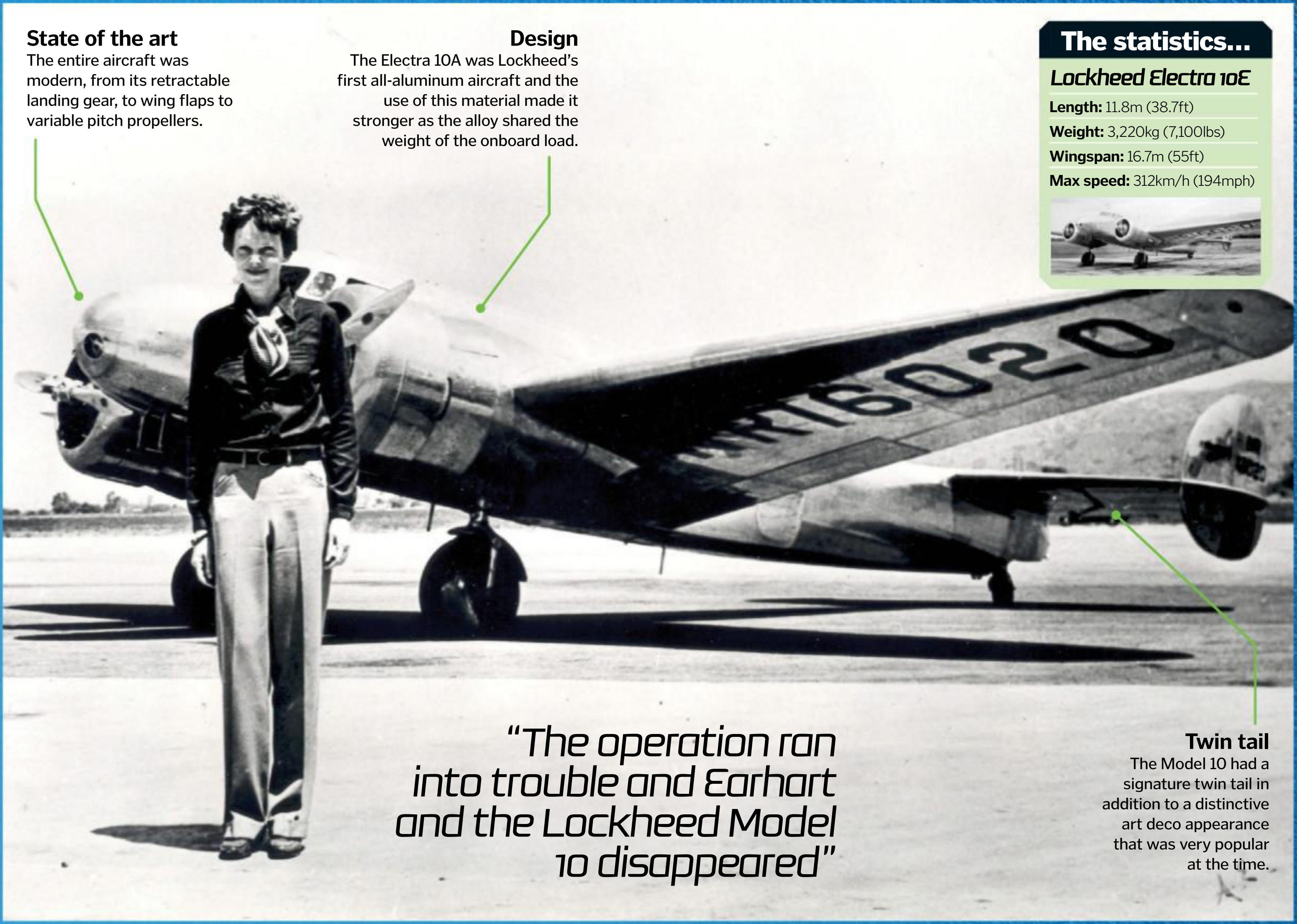
Years in service: One

'Enola Gay;' and 'Little Boy'. Two names that are now synonymous with changing the city of Hiroshima and the whole world forever. Named after pilot Paul W. Tibbets' mother, Enola Gay was a B-29 bomber built under the top-secret 'Silverplate' programme. Part of a batch of 15 bombers, it was chosen to fly the first ever atomic combat mission. The weapon would be known as 'Little Boy' and was a 15-kiloton bomb. Taking off at 2.45am local time, it arrived in Iwo Jima at 6.05am and armed its payload. After Little Boy was dropped 11.5 miles from the detonation point, the aircraft turned to make its hasty escape. As the atomic bomb sent Hiroshima to oblivion, Enola Gay was rocked by several after shocks as it withdrew. The crew remember seeing the resulting mushroom cloud for an hour and half afterwards as the aircraft returned to base, mission accomplished. Unknown to many, Enola Gay actually went on a second mission later the same month to scout out the target for the second atomic bombing mission. Today it is housed in the US National Air and Space Museum but will always be remembered for that devastating day in the summer of 1945.

DID YOU KNOW? *Amelia Earhart was only the 16th woman in the world to be issued a pilot's license*

Lockheed M10 Electra

Often overshadowed by its infamous pilot, the Lockheed Model 10 was still an iconic aircraft



State of the art
The entire aircraft was modern, from its retractable landing gear, to wing flaps to variable pitch propellers.

Design
The Electra 10A was Lockheed's first all-aluminum aircraft and the use of this material made it stronger as the alloy shared the weight of the onboard load.

Twin tail
The Model 10 had a signature twin tail in addition to a distinctive art deco appearance that was very popular at the time.

The statistics…

Lockheed Electra 10E

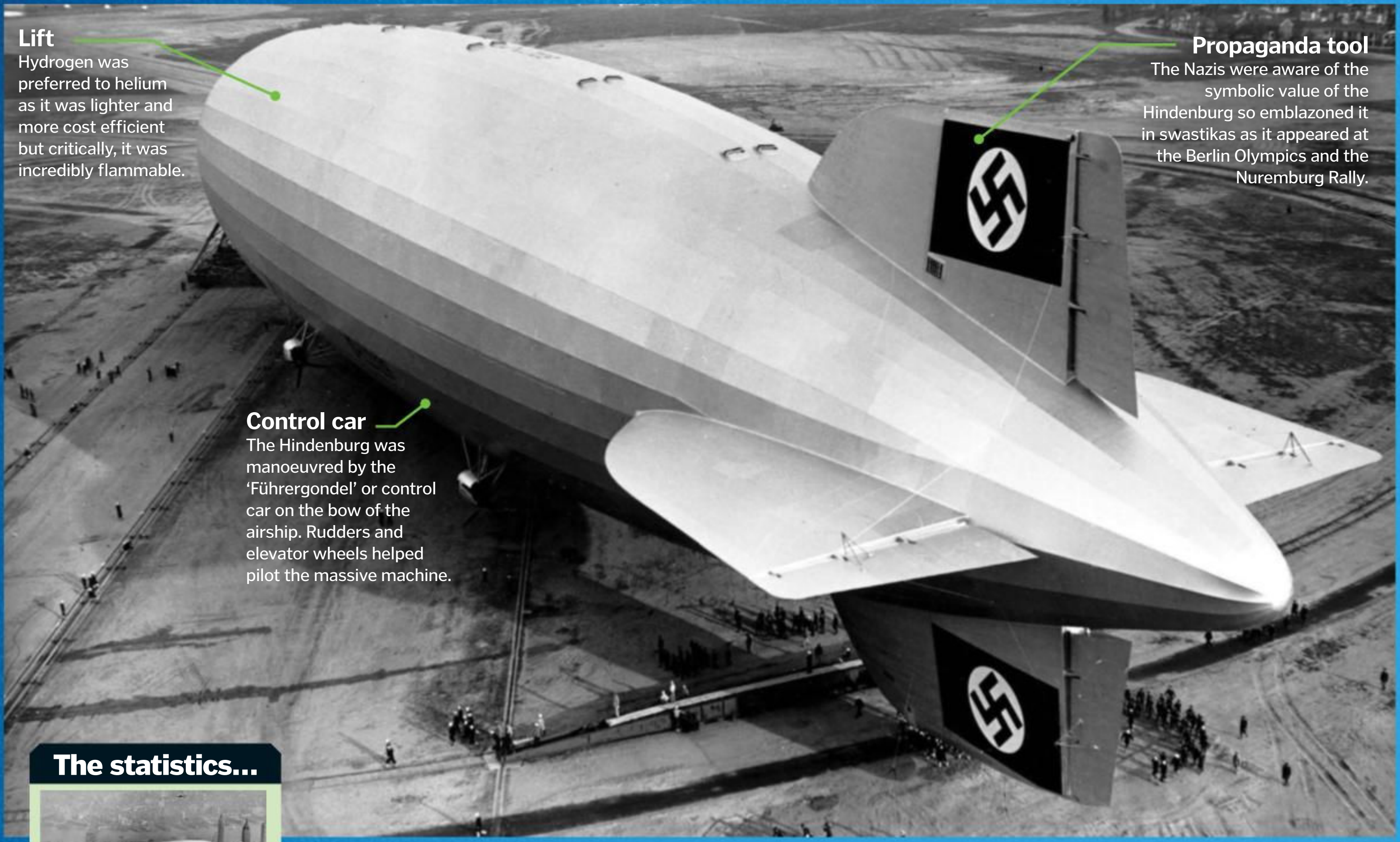
Length: 11.8m (38.7ft)
Weight: 3,220kg (7,100lbs)
Wingspan: 16.7m (55ft)
Max speed: 312km/h (194mph)

> *"The operation ran into trouble and Earhart and the Lockheed Model 10 disappeared"*

Built as a response to the Douglas DC-2 and the Boeing 247, Lockheed was one of the companies transforming commercial aviation in interwar USA. Twin engine, the plane was originally intended for commercial use and could accommodate ten passengers and two crew. Before being used by Earhart, Northwest Airlines flew the plane in its fleet in the late 1930s and it was also taken on by European and Australian firms. The aircraft's most famous moment however, was undoubtedly its final journey. The plane used on the voyage was actually a modified version of the original model. More fuel tanks were added to the aircraft, increasing the carrying capacity and also the electronics were altered to add radio direction finders, which was state of the art at the time. Piloted by young pilot Amelia Earhart, the mission was simple; fly around the world. Tragically, the operation ran into trouble and Earhart and the Lockheed Model 10 disappeared in mysterious circumstances in October 1937. The reasons are still debated to why Earhart and her navigator Fred Noonan disappeared on the final leg of their journey with reasons ranging from a lack of fuel to a crash landing.

LZ 129 Hindenburg

This colossal machine is an example of a bygone era of aviation



Lift
Hydrogen was preferred to helium as it was lighter and more cost efficient but critically, it was incredibly flammable.

Propaganda tool
The Nazis were aware of the symbolic value of the Hindenburg so emblazoned it in swastikas as it appeared at the Berlin Olympics and the Nuremburg Rally.

Control car
The Hindenburg was manoeuvred by the 'Führergondel' or control car on the bow of the airship. Rudders and elevator wheels helped pilot the massive machine.

The statistics…

LZ 129 Hindenburg

Launch date: 4 March 1936

Length: 245m (803.8ft)

Diameter: 41.2m (135.1ft)

Max speed: 135km/h (84mph)

Crew: 40 flight officers, 12 stewards and cooks

Years in service: One year and two months

In the first few decades of the 20th century, giant airships filled the sky. They were the preferred transport of the rich and famous and were particularly popular in Germany, where Zeppelin airships were all the rage. The Hindenburg was constructed solely for transcontinental transportation and after its maiden flight, became the largest object ever to fly at a mammoth 2.1 million cubic metres (7 million cubic feet). The airship finally got airborne after financial support by the Nazi Government and its maiden flight to the USA occurred on 31 March 1936. By the end of the year it had crossed the Atlantic 34 times carrying both passengers and cargo. It even had an autopilot system that could keep the ship on course in stable weather conditions. All seemed to be going well for the new technology but disaster would strike on 6 May 1937. When flying over Lakehurst, New Jersey an electrostatic discharge ignited with leaking hydrogen, causing the Hindenburg to explode dramatically. Miraculously, only 35 of the 97 passenger crew died with the majority just escaping with their lives. The disaster sent shockwaves across the world and the zeppelin industry never recovered. The age of transatlantic airship travel was over before it really began.

DID YOU KNOW? *The inspiration for the Fokker came after a British Sopwith aircraft crashed behind enemy lines*

Fokker Dr.I

The most famous German aircraft of the Great War and the triplane of choice for the Red Baron

The statistics…

Fokker DR.I

Launch date: 1917

Length: 5.77m (18.93ft)

Weight: 406kg (895lb)

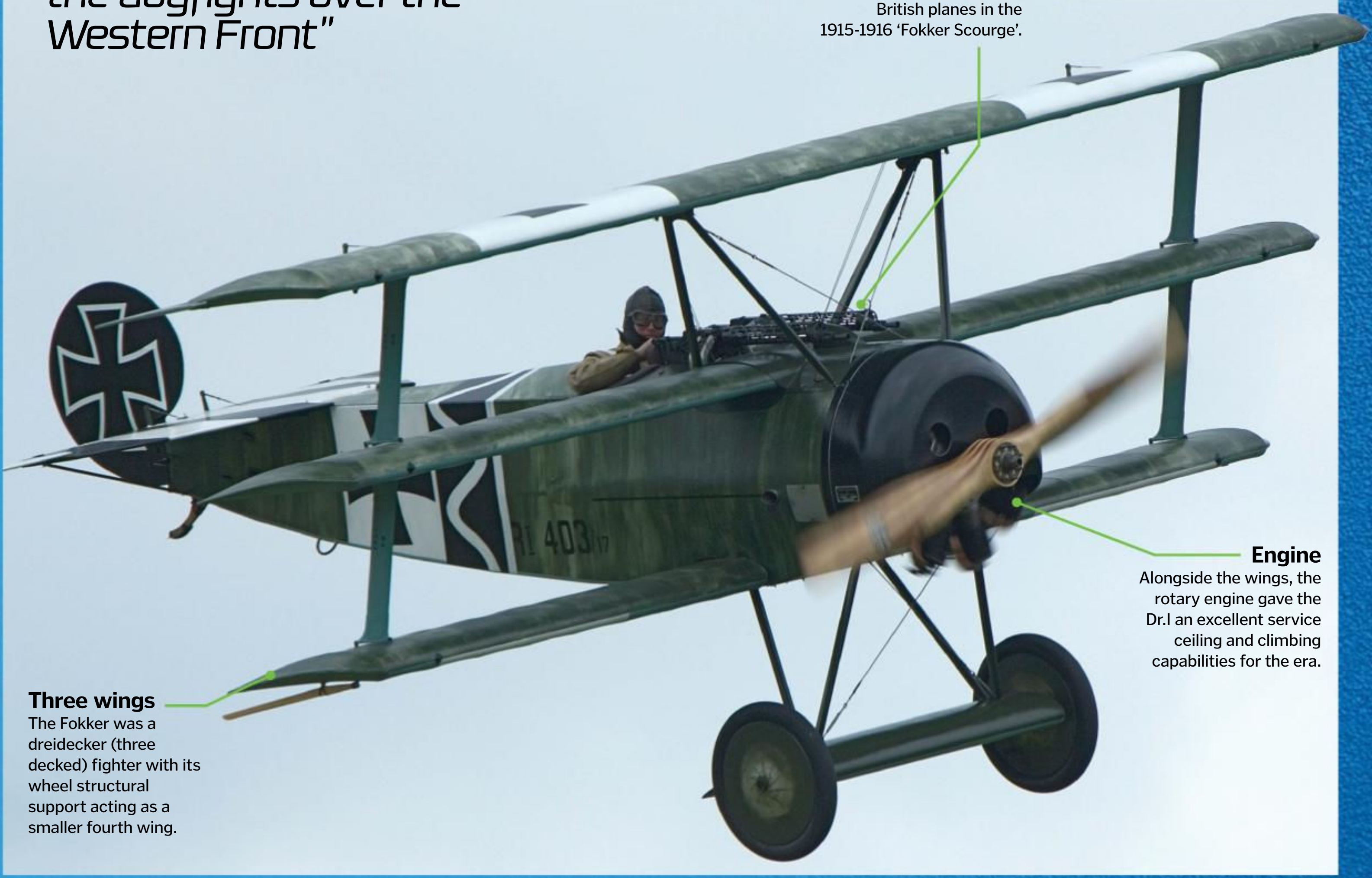
Wingspan: 7.20m (23.62ft)

Max speed: 165km/h (103mph)

Max altitude: 6,095 miles (19,997ft)

Number produced: 320

> *"The fighter remains an evocative symbol of the dogfights over the Western Front"*



Firepower
The German pilots wielded twin 7.92mm Spandau LMG 08/15 machine guns that would cause mayhem to the British planes in the 1915-1916 'Fokker Scourge'.

Engine
Alongside the wings, the rotary engine gave the Dr.I an excellent service ceiling and climbing capabilities for the era.

Three wings
The Fokker was a dreidecker (three decked) fighter with its wheel structural support acting as a smaller fourth wing.

Remembered as one of the greatest aircraft of the First World War, the Fokker DR.I filled British and French hearts with dread. Powerful and highly manoeuvrable, opposing pilots quickly learnt that it was not be taken lightly, especially when it was being piloted by Manfred von Richthofen, the German fighter ace nicknamed 'the Red Baron'. As the war progressed, the triplane was hampered by structural issues and only 320 were produced. It could only last for a total of 80 minutes in the air on one tank of fuel and they were grounded completely for a period in the winter of 1917 when the wing attachment points were considered far too weak when in flight. Part of the Jagdgeschwader 1 fighter unit, the Dr.I returned to the skies in the spring of 1918 but was only ever truly effective in the hands of skilled pilots, so never made it as the main aircraft in the German air force, the Luftstreitkräfte. However, the fighter remains an evocative symbol of the dogfights over the Western Front and the bright red edition piloted by the formidable Red Baron.

Apache Helicopter

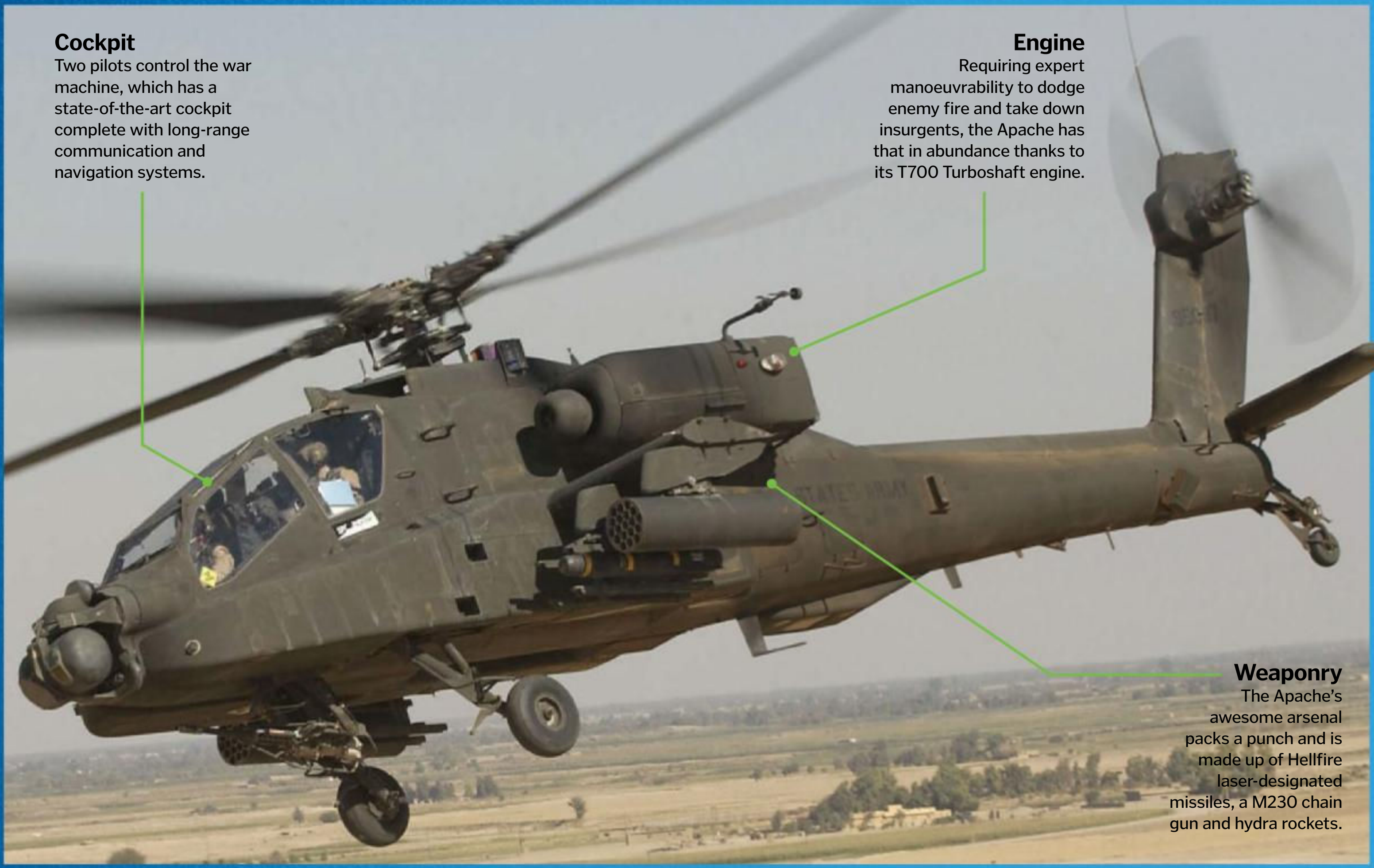
Destructive on land, sea and air, the Apache isn't far off being the ultimate military machine

The statistics…

Boeing AH-64 Apache

Launch date: 1984
Length: 17.73m (58.17ft)
Weight: 6,838kg (15,075lb)
Max speed: 279km/h (173mph)
Years in service: 30

A nightmare for tanks and ground troops alike, the Apache has revolutionised modern warfare. An immensely powerful war machine, the Apache is feared across the globe and can spring into action at any time, day or night, rain or shine. The AH-64 is a stalwart of the US and British militaries and has been used with great success in Iraq, Afghanistan and Kosovo. The Gulf War in particular saw the Apache come into its own, with the Iraqi tanks no match for a combined AH-64 and F-117 Nighthawk stealth fighter assault. The gunship is effective on land, sea and air and is able to quickly respond to any skirmish, making it an ideal rapid response unit that can lead counterattacks. The design has proved so popular that it has been developed and improved on in various other models that can be used in almost any terrain. It has also caught the attention of a number of other militaries around the world with Israel, Greece, Japan and the Netherlands all incorporating Apaches into their ranks. Boeing (known as MacDonnell Douglas at the time of the first Apache) was given a £158 ($247) million contract in 2010 to build even more of these beasts for use in global peacekeeping.



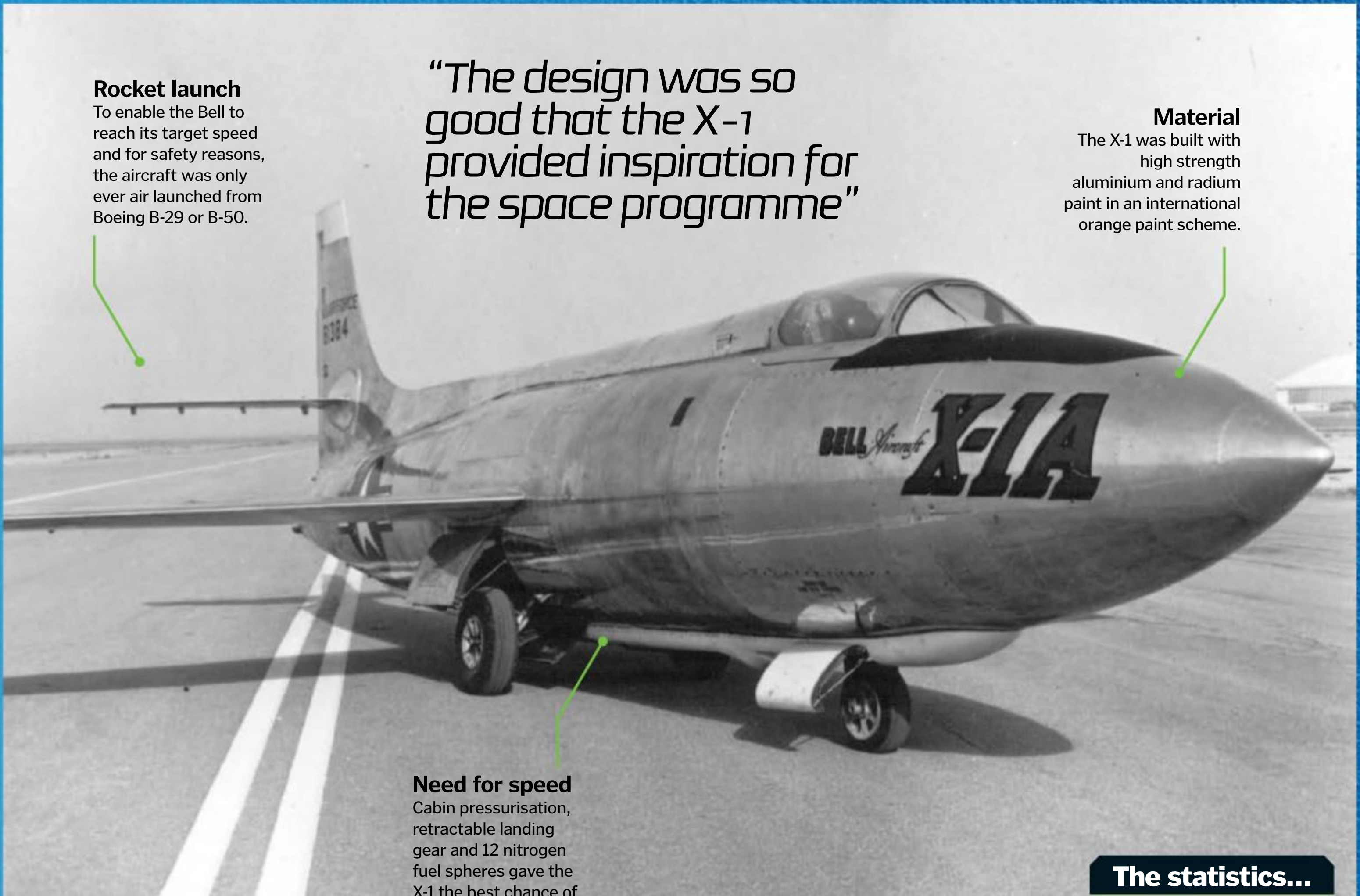
Cockpit
Two pilots control the war machine, which has a state-of-the-art cockpit complete with long-range communication and navigation systems.

Engine
Requiring expert manoeuvrability to dodge enemy fire and take down insurgents, the Apache has that in abundance thanks to its T700 Turboshaft engine.

Weaponry
The Apache's awesome arsenal packs a punch and is made up of Hellfire laser-designated missiles, a M230 chain gun and hydra rockets.

Bell X-1

The first plane to go supersonic, the Bell X-1 smashed the sound barrier in 1947



Rocket launch
To enable the Bell to reach its target speed and for safety reasons, the aircraft was only ever air launched from Boeing B-29 or B-50.

> *"The design was so good that the X-1 provided inspiration for the space programme"*

Material
The X-1 was built with high strength aluminium and radium paint in an international orange paint scheme.

Need for speed
Cabin pressurisation, retractable landing gear and 12 nitrogen fuel spheres gave the X-1 the best chance of achieving its goal.

US Air Force pilot, Captain Charles E Yeager, broke the speed of sound on the 14 October 1947 in this very aircraft. Attaining a speed of 1,127 kilometres (700 miles) per hour or Mach 1.06, the plane, nicknamed Glamorous Glennis after the pilot's wife, entered the record books. The X-1 wasn't launched in the orthodox way and was instead propelled via air-launch from the bomb bay of a Boeing B-29. The record attempt wasn't the last of the X-1's record breakers, though. On 26 March 1948, it reached the highest velocity and altitude of a manned airplane up to that time. A single engine, single seat aircraft, 'Glennis', broke all idea of a sound barrier using a liquid fuelled 6,000-pound thrust rocket engine. The aircraft was one of a kind, shaped like a .50-caliber bullet – a round that was stable in supersonic flight when fired from a gun. The design was so good that the X-1 programme helped provide the inspiration for the space programme that would begin in subsequent decades. One of the most important aircraft of all time, the Bell X-1 ushered in a new era; the supersonic age.

The statistics…

Bell X-1

Launch date: 1946

Length: 9.45m (31ft)

Weight: 3,674kg (8,100lb)

Wingspan: 8.54m (28ft)

Max speed: 1,540km/h (957mph)/ Mach 1.45

Max altitude: 21,900m (71,900ft)

Supermarine Spitfire

The heroic British fighter of World War Two that took the fight in the skies back to the German Luftwaffe

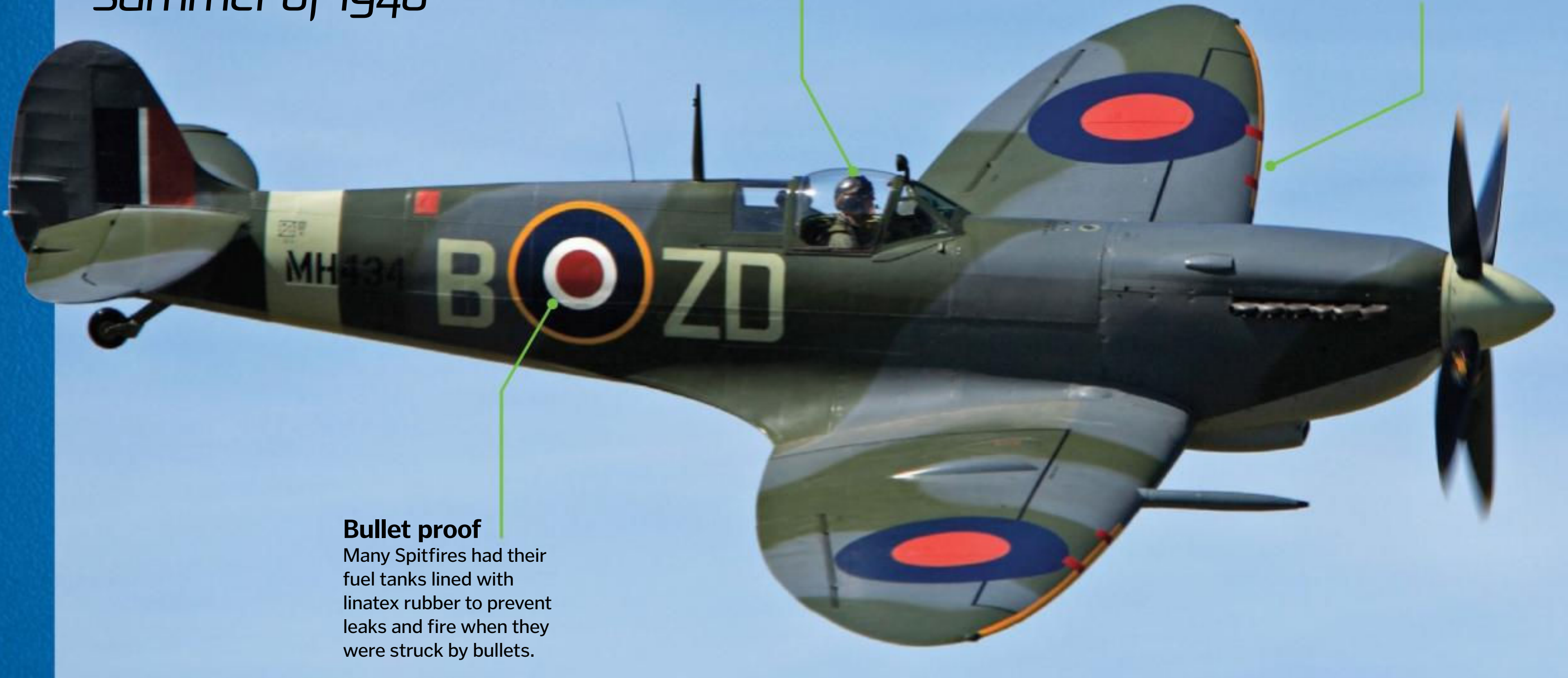
One of the most enduring images of the Second World War, the Spitfire is credited with saving the British Isles from the threat of German invasion. Fast, manoeuvrable and with an iconic engine sound, the Spitfire combined well with the Hawker Hurricane against the threat of the Messerschmitts. The Battle of Britain wasn't the Spitfire's only major contribution. It served the Allies with distinction over the course of the war, becoming the most widely produced British fighter of the war. It was constantly upgraded to battle the best the Luftwaffe had to offer and fought in every theatre of the war. D-Day and the invasion of Sicily wouldn't have happened if it wasn't for the excellent air support the Spitfire's provided. A Seafire version was created specifically for use in the Royal Navy on aircraft carriers and they became invaluable in the battle in the Pacific against Japan. Quintessentially British, the Spitfire was sold to various air forces around the world after the war but remains an icon of plucky British resistance in the summer of 1940. It is estimated that over 20,000 Spitfires were made and around 50 are still flying today as its legendary status lives on.

The statistics...

Supermarine Spitfire

Launch date: 1936
Length: 9.12m (29.11ft)
Weight: 2,257kg (4,976lb)
Wingspan: 11.23m (36.10ft)
Max speed: 584km/h (362mph)
Max altitude: 10,668m (35,00ft)
Years in service: 19

> *"The Spitfire remains an icon of plucky British resistance in the summer of 1940"*



High flyer
As well as being a more than capable fighter, the Spitfire's high service ceiling allowed it to be an effective reconnaissance aircraft, gathering valuable enemy information.

Strategy
Boasting superior manoeuvrability, Spitfires would take down the more nimble German fighters while the Hurricanes went for the Luftwaffe bombers.

Bullet proof
Many Spitfires had their fuel tanks lined with linatex rubber to prevent leaks and fire when they were struck by bullets.

DID YOU KNOW? *The first aircraft to make a solo transatlantic flight, the St Louis stayed in the air for 33.5 hours!*

Spirit of St Louis

With a prize of $25,000, US pilot Charles Lindbergh jumped at the chance to pilot the famous monoplane

The statistics…

Spirit of St Louis

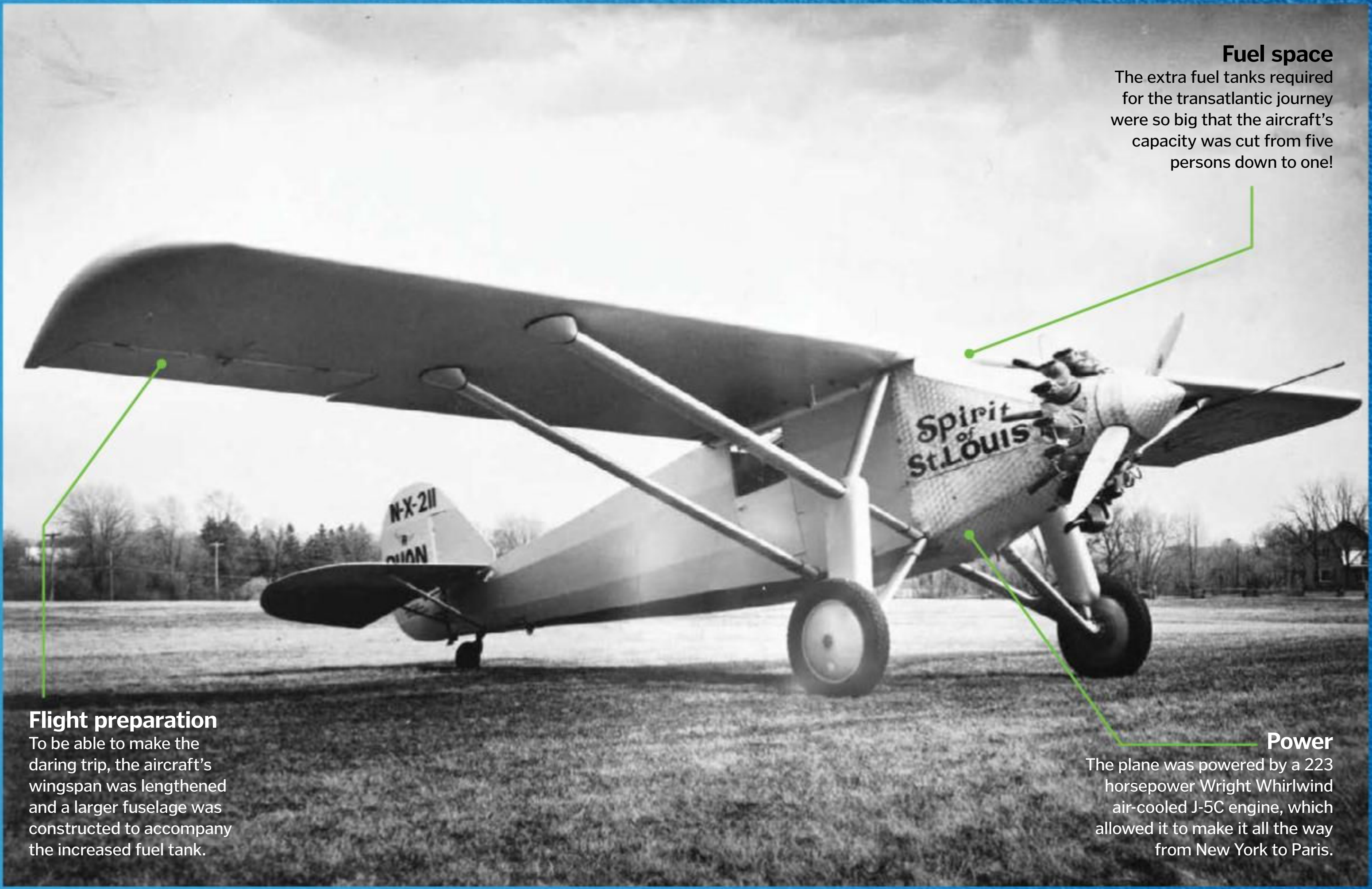
Launch date: 1927

Length: 8.41m (27.7ft)

Weight: 2,330kg (5,135lb)

Wingspan: 14.02m (46ft)

Max speed: 200km (120 miles)



Fuel space
The extra fuel tanks required for the transatlantic journey were so big that the aircraft's capacity was cut from five persons down to one!

Flight preparation
To be able to make the daring trip, the aircraft's wingspan was lengthened and a larger fuselage was constructed to accompany the increased fuel tank.

Power
The plane was powered by a 223 horsepower Wright Whirlwind air-cooled J-5C engine, which allowed it to make it all the way from New York to Paris.

After the Wright Brothers and their contemporaries had made flight achievable, aviators competed to take aviation to an even higher level. Charles A. Lindbergh was one of these men and in May 1927 competed for $25,000 to be the first to cross the Atlantic non-stop. French hotel owner Raymond Orteig had a great passion for flying and offered the best pilots in the world the cash prize. Lindbergh and the Spirit of St Louis were the ideal team to undertake the task. The plane had been specifically constructed for the mission and in test flights it managed to break the transcontinental record by flying from San Diego to New York in 21 hours and 40 minutes. Any item that wasn't needed was removed so Lindbergh was forced to fly with no radio, parachute or navigation lights! The historic journey was made between 20-21 May and the Spirit of St Louis was in such good shape, it was constantly flown around the Americas for years by Lindbergh to increase interest in aeronautics. The plane is now at the Smithsonian National Air and Space Museum in Washington DC, forever an icon.

Wingspan
To provide enough lift, the Stratolaunch has a wingspan longer than the total height of the Apollo Saturn V rocket.

SKY GIANTS

Discover how the world's biggest aircraft combine clever engineering and advanced materials to defy gravity

The first powered flight in 1903, by Orville Wright, covered a distance of just 37 metres (121 feet). He could have taken off and landed – twice – across the wings of an Airbus A380. In the 110 years since that flight, engines have moved from pistons to turbo jets; construction materials have switched from wood and cloth to aluminium alloys and carbon fibre; and wing design has dropped the draughtsman's table in favour of computational fluid dynamics.

For passenger aircraft, increasing size offers greater economies of scale; large planes can fly farther without stopping and they use less fuel per passenger-mile. That's true for cargo planes as well but truly huge cargo planes can carve themselves a niche even when the cost per ton is higher. That's because some loads are just so massive they can *only* be carried by the largest planes. The heaviest, the widest, the longest or simply the largest, the aircraft included here can all claim to be the biggest in the world, according to some criterion. What they all have in common, though, is jaw-dropping specs. Whether you need to airlift a downed Chinook helicopter from a warzone or send off a 220-ton shuttle into space, there's always going to be a demand for mega-planes like these…

KEY DATES
AVIATION MILESTONES

1907 The Breguet-Richet gyroplane makes the first manned helicopter 'flight', although it is tethered to the ground.

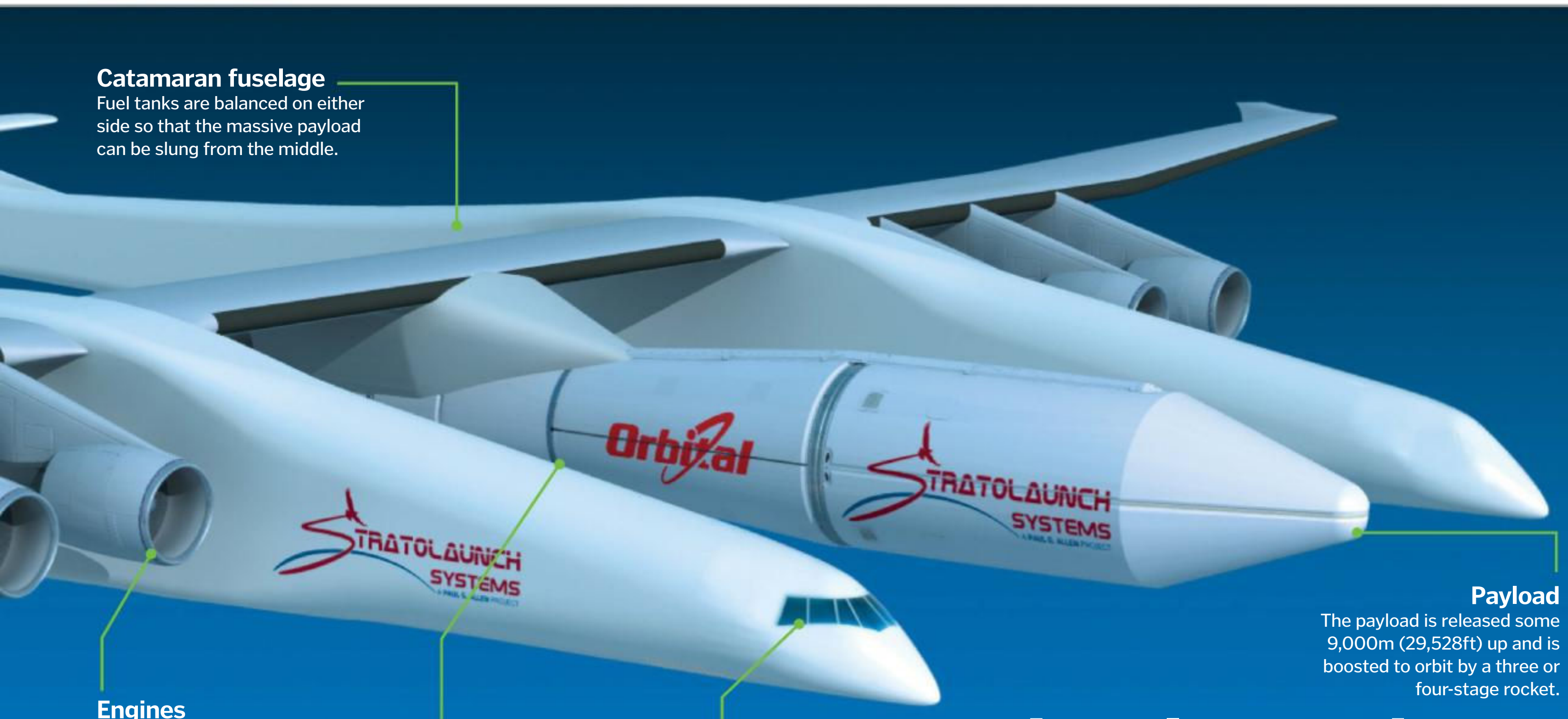
1933 The first true airliner, a Boeing 247, carries ten passengers from New York to LA in 20 hours.

1939 Heinkel He 178, the first turbojet aircraft, flies. It reaches speeds of over 644km/h (400mph).

1964 The test vehicle for the Apollo Lunar Lander is the first electronic fly-by-wire aircraft with no hydraulic backup.

1986 Dick Rutan and Jeana Yeager fly around the world without refuelling in the Rutan Voyager.

DID YOU KNOW? *Boeing's 747 fleet has flown more than 5.6bn passengers – equal to 80 per cent of the world's population*



Catamaran fuselage
Fuel tanks are balanced on either side so that the massive payload can be slung from the middle.

Payload
The payload is released some 9,000m (29,528ft) up and is boosted to orbit by a three or four-stage rocket.

Engines
The six jet engines are cannibalised from a pair of used 747-400 planes. The total thrust is 252kN (56,750lbf).

Integration system
Developed by Dynetics Inc, which has extensive experience with air launch systems used on military missile systems.

Cockpit
The fully fly-by-wire system balances the control inputs to compensate for the off-centre pilot's position.

Wings longer than a soccer pitch
Stratolaunch

Funded by Paul Allen, co-founder of Microsoft, the Stratolaunch is still at the design stage. But if it is ever built, it will have the largest wingspan of any aircraft ever made. Taking off from a runway almost 3.7 kilometres (2.3 miles) long, it will climb to 9,000 metres (29,530 feet) before releasing a 220-ton rocket that will fly the rest of the way into orbit. Launching rockets this way avoids the thickest part of the atmosphere and grants a greater choice of possible orbital trajectories. It effectively turns the Stratolaunch into a reusable first-stage booster.

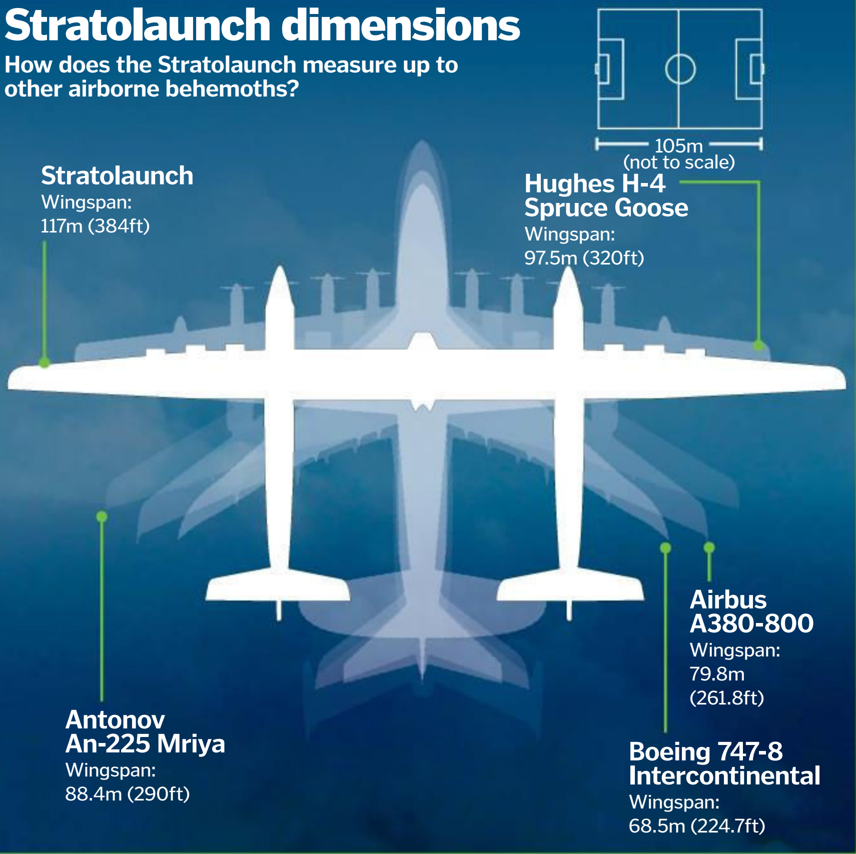
The technical challenges, however, are formidable. Air-launching rockets isn't new; the early test flights of the Space Shuttle involved the Enterprise being launched from the back of a 747. But the Shuttle was a glider, empty of fuel and only weighed 68 tons. The Pegasus II rocket carried by Stratolaunch weighs more than three times this and is full of explosive rocket fuel. Stratolaunch also needs to pull into a steep climb just before releasing the rocket, without plunging itself into a fatal stall. Designing an airframe to cope with these strains will push aviation technology to the limits.

The statistics...

Stratolaunch

Length: 71.6m (235ft)
Wingspan: 117m (385ft)
Capacity: 226,800kg (500,000lb)
Max takeoff weight: 590,000kg (1.3mn lb)
Range: 1,850km (1,150mi)
Estimated cost: £178mn ($300mn)

Stratolaunch dimensions
How does the Stratolaunch measure up to other airborne behemoths?



Stratolaunch
Wingspan: 117m (384ft)

Hughes H-4 Spruce Goose
Wingspan: 97.5m (320ft)

Airbus A380-800
Wingspan: 79.8m (261.8ft)

Antonov An-225 Mriya
Wingspan: 88.4m (290ft)

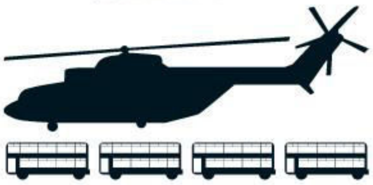
Boeing 747-8 Intercontinental
Wingspan: 68.5m (224.7ft)

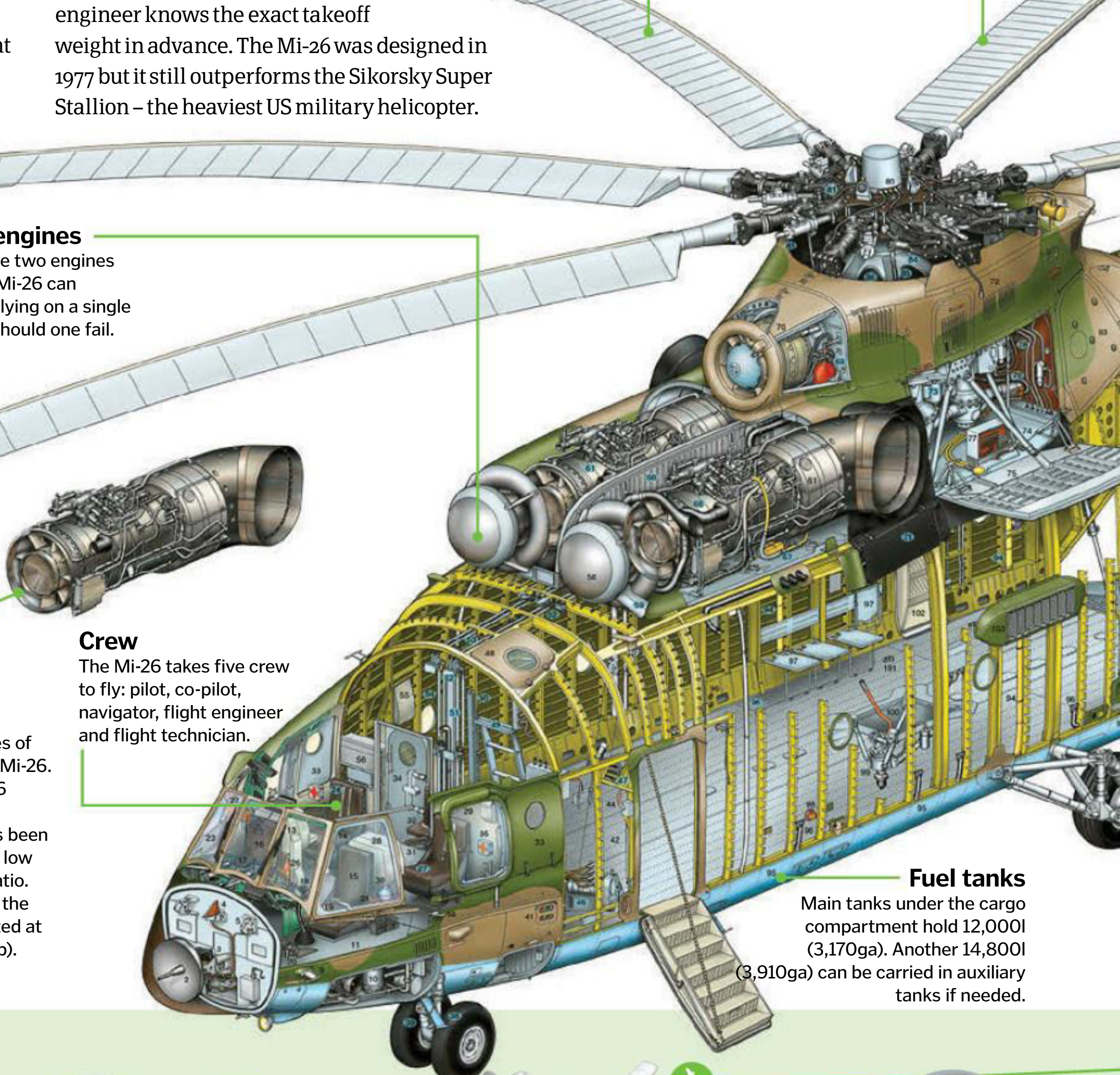
> "Each main wheel has a weight sensor so the flight engineer knows the exact takeoff weight"

Mammoth transporter

Mi-26 helicopter

The Russian Mi-26 is the largest helicopter in the world and the one with the greatest lifting capacity. The cargo compartment can fit a fire engine or 150 troops. It can be outfitted as a flying hospital with its own operating theatre, pre-op section, medical lab, restroom, changing area and space for 60 stretchers. For really mammoth loads (see 'Did you know?'), there's an exterior sling rated to lift 20 tons. The total takeoff weight of the Mi-26, including fuel and cargo, is 56 tons and the power to keep it all aloft is supplied by twin turboshaft engines. Lifting such enormous loads needs precision too. The winch mechanism is positioned in line with the main rotor, to avoid unbalancing the helicopter, and includes a video link so the pilot can keep an eye on the dangling cargo. Each of the three main wheels also has a weight sensor so the flight engineer knows the exact takeoff weight in advance. The Mi-26 was designed in 1977 but it still outperforms the Sikorsky Super Stallion – the heaviest US military helicopter.





Eight blades
The Mi-26 was the first production helicopter in the world to use eight blades off a single rotor.

Heated rotors
All the rotors are fitted with electro-thermal anti-icers to stop them freezing at high altitude.

Twin engines
There are two engines but the Mi-26 can remain flying on a single engine should one fail.

Engine
There are two types of engine used in the Mi-26. The standard D-136 provides 8,500kW (11,400hp) and has been designed to have a low weight-to-power ratio. Newer models use the D-136-2 engine, rated at 9,321kW (12,500hp).

Crew
The Mi-26 takes five crew to fly: pilot, co-pilot, navigator, flight engineer and flight technician.

Fuel tanks
Main tanks under the cargo compartment hold 12,000l (3,170ga). Another 14,800l (3,910ga) can be carried in auxiliary tanks if needed.

The statistics…

Mi-26

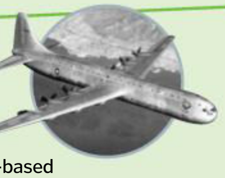
Length: 40m (131ft)
Rotor span: 32m (105ft)
Capacity: 20,000kg (44,100lb)
Max takeoff weight: 56,000kg (123,460lb)
Max speed: 295km/h (183mph)
Cost: £6.5mn ($11mn)

Giants that never took off…

Kennedy Giant 1917
This 8.5-ton British biplane bomber's four engines only had enough power to fly in a straight line. It was cancelled after a single test flight.

Blohm & Voss BV 238 1944
Built by the Germans during WWII, it was a 55-ton seaplane armed with 22 machine guns. The only one built was sunk while docked at Lake Schaalsee, Germany.

Spruce Goose 1947
To save wartime aluminium, this seaplane was built from wood. It was intended as a troop transport but it weighed 113 tons empty and even its 97.5m (320ft) wingspan could barely get it airborne.



Convair XC-99 1947
The largest piston-engined land-based carrier plane ever built. It weighed 61 tons and could carry 45,000kg (99,208lb). Only one was made, but it remained in service for ten years.

HEAD 2 HEAD
HELICOPTER HEAVYWEIGHTS

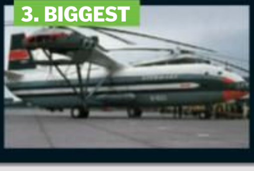
1. BIG

Hughes XH-17
The Flying Crane was an experimental helicopter built in 1952. It had the largest rotor span ever at 40.8m (134ft).

2. BIGGER

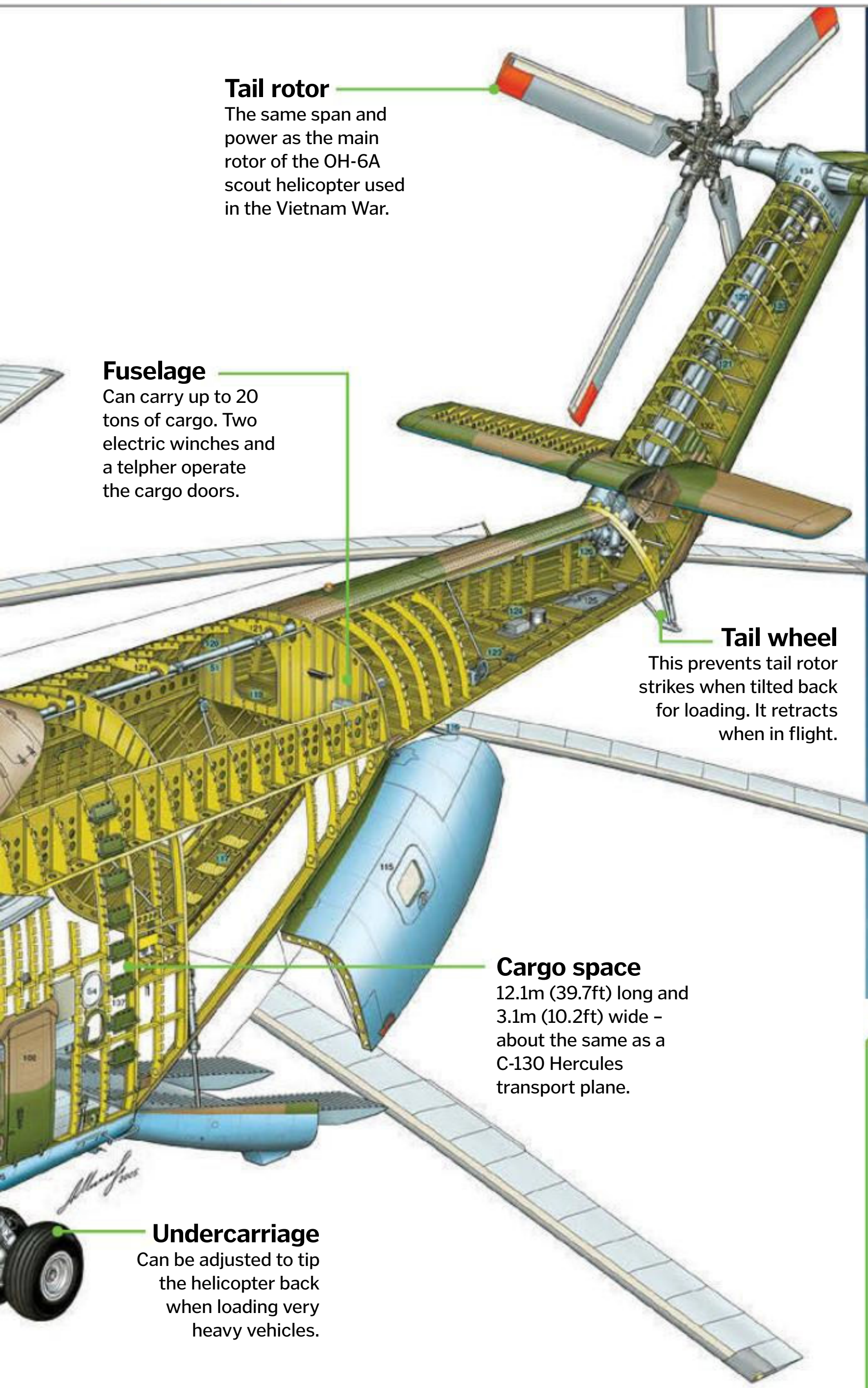
Sikorsky CH-53E
The Super Stallion is the largest helicopter in the US military. Lift capacity is 13.6 tons internally or 14.5 tons externally.

3. BIGGEST



Mil V-12
Although it never went into production, the Mil V-12 was the largest helicopter ever to be built. It could lift a mind-boggling 40 tons!

DID YOU KNOW? *In 1999 a Mi-26 was used to carry a 25-ton block of ice containing a frozen woolly mammoth!*



Tail rotor
The same span and power as the main rotor of the OH-6A scout helicopter used in the Vietnam War.

Fuselage
Can carry up to 20 tons of cargo. Two electric winches and a telpher operate the cargo doors.

Tail wheel
This prevents tail rotor strikes when tilted back for loading. It retracts when in flight.

Cargo space
12.1m (39.7ft) long and 3.1m (10.2ft) wide – about the same as a C-130 Hercules transport plane.

Undercarriage
Can be adjusted to tip the helicopter back when loading very heavy vehicles.

A Mi-26 carrying a Tu-134 airliner without breaking a sweat

World's biggest hangars

As you'd expect, the biggest aircraft in the world need the biggest hangars to keep them out of the elements during inspection and maintenance. One of the largest hangars in a commercial airport belongs to the Dubai Royal Airwing. It has space for eight planes, including three Airbus A380s, with doors that are over 580 metres (1,903 feet) wide. The largest building for a single aeroplane, though, is the one-hectare (2.4-acre) Stratolaunch hangar in Mojave, CA.

Once you include airships, the sizes jump way up. The Cardington airsheds in Bedfordshire, used for Airlander, for instance, are 1.4 hectares (3.4 acres) each, while Hangar One at the US Naval Air Station in Sunnyvale, CA, covers 3.2 hectares (eight acres).

The biggest of them all isn't a hangar any more. It was built for the abandoned CargoLifter CL160 airship and you could park the Eiffel Tower on its side within it. It has been turned into a holiday resort.

Bristol Brabazon 1949
A British transatlantic passenger jet. It had a larger wingspan than a 747 and four pairs of contra-rotating propellers. Built for luxury, each passenger had as much space as the interior of a car, which made it hopelessly uneconomical.

Convair X-6 1958
The idea was to mount nuclear-powered engines in a converted B-36 bomber. The plane would have been able to fly continuously for several weeks but the crew required 12 tons of lead and rubber shielding to protect them from the deadly radiation!

Boeing NLA 1993
The New Large Aircraft (NLA) would have seated over 600 passengers, with a maximum takeoff weight of 635.6 tons. However, Boeing abandoned the design to concentrate on 747 derivatives.

Boeing Pelican 2002
This transport design concept could fly like a plane if necessary, but would mostly skim just 6m (20ft) above the surface of the sea. It would have been able to carry around 1,400 tons of cargo.

> "Boeing responded by developing the 747-8, now the world's longest passenger airliner"

Battle of the airliners

Boeing 747 vs Airbus A380

The Boeing 747 and Airbus A380 are in direct competition for long-haul flights, both for passengers and cargo. When the A380 was first developed, it topped the most common 747 variant, the 747-400, in almost every way apart from price. But Boeing responded in 2008 by developing the 747-8, which is now the world's longest passenger airliner and the heaviest aircraft of any kind to be manufactured in the US. Although it has a smaller passenger capacity than the A380, the gap has shrunk considerably and the 747-8 is lighter, which means it uses less fuel. For airline companies, this makes the 747-8 a considerable 21 per cent cheaper to fly for each trip. However, the A380 is quieter. In fact, it is the quietest wide-body airliner in service, producing only half the noise of a 747 on takeoff. The A380 has also been marketed as more luxurious. The cabin area can be configured with shops, a restaurant and even a beauty salon for passengers. But so far, commercial airline companies have preferred additional seating over luxury and this is still the biggest selling point of the A380.

The statistics...

Airbus A380

Length: 72.7m (238.5ft)

Wingspan: 79.8m (261.8ft)

Capacity: 853 passengers

Max takeoff weight: 560,000kg (1.23mn lb)

Max speed: 945km/h (587mph)

Cost: £240mn ($404mn)

The 747 reinvented

The latest in the Boeing jumbo jet family, the 747-8 has received plenty of upgrades

The statistics...

Boeing 747-8

Length: 76.3m (250.3ft)

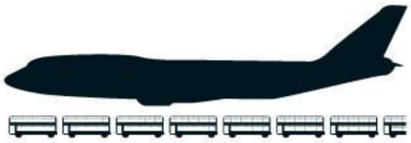
Wingspan: 68.5m (224.7ft)

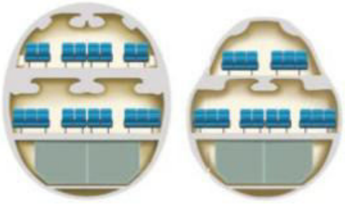
Capacity: 605 passengers

Max takeoff weight: 448,000kg (987,670lb)

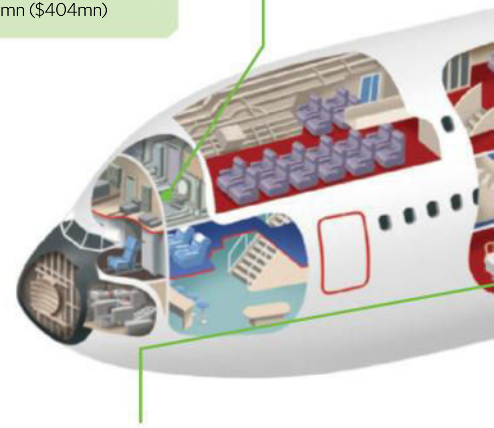
Max speed: 988km/h (614mph)

Cost: £212mn ($357mn)



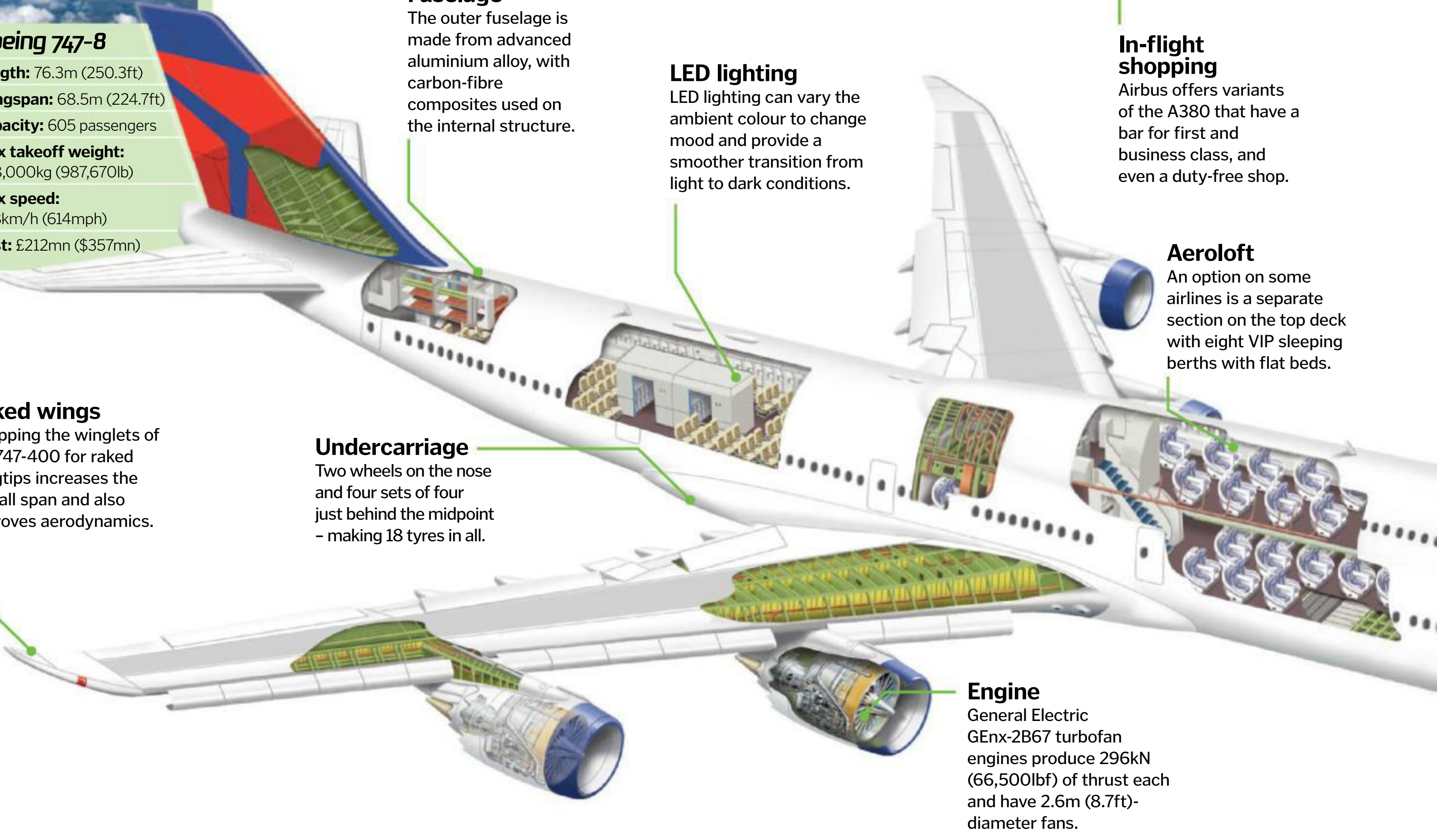


The inside layout of an A380 (left) and a 747-8 (right)



Fly by wire
The A380 is steered with a computer joystick to the side of the pilot's seat.

In-flight shopping
Airbus offers variants of the A380 that have a bar for first and business class, and even a duty-free shop.



Fuselage
The outer fuselage is made from advanced aluminium alloy, with carbon-fibre composites used on the internal structure.

LED lighting
LED lighting can vary the ambient colour to change mood and provide a smoother transition from light to dark conditions.

Aeroloft
An option on some airlines is a separate section on the top deck with eight VIP sleeping berths with flat beds.

Raked wings
Swapping the winglets of the 747-400 for raked wingtips increases the overall span and also improves aerodynamics.

Undercarriage
Two wheels on the nose and four sets of four just behind the midpoint – making 18 tyres in all.

Engine
General Electric GEnx-2B67 turbofan engines produce 296kN (66,500lbf) of thrust each and have 2.6m (8.7ft)-diameter fans.

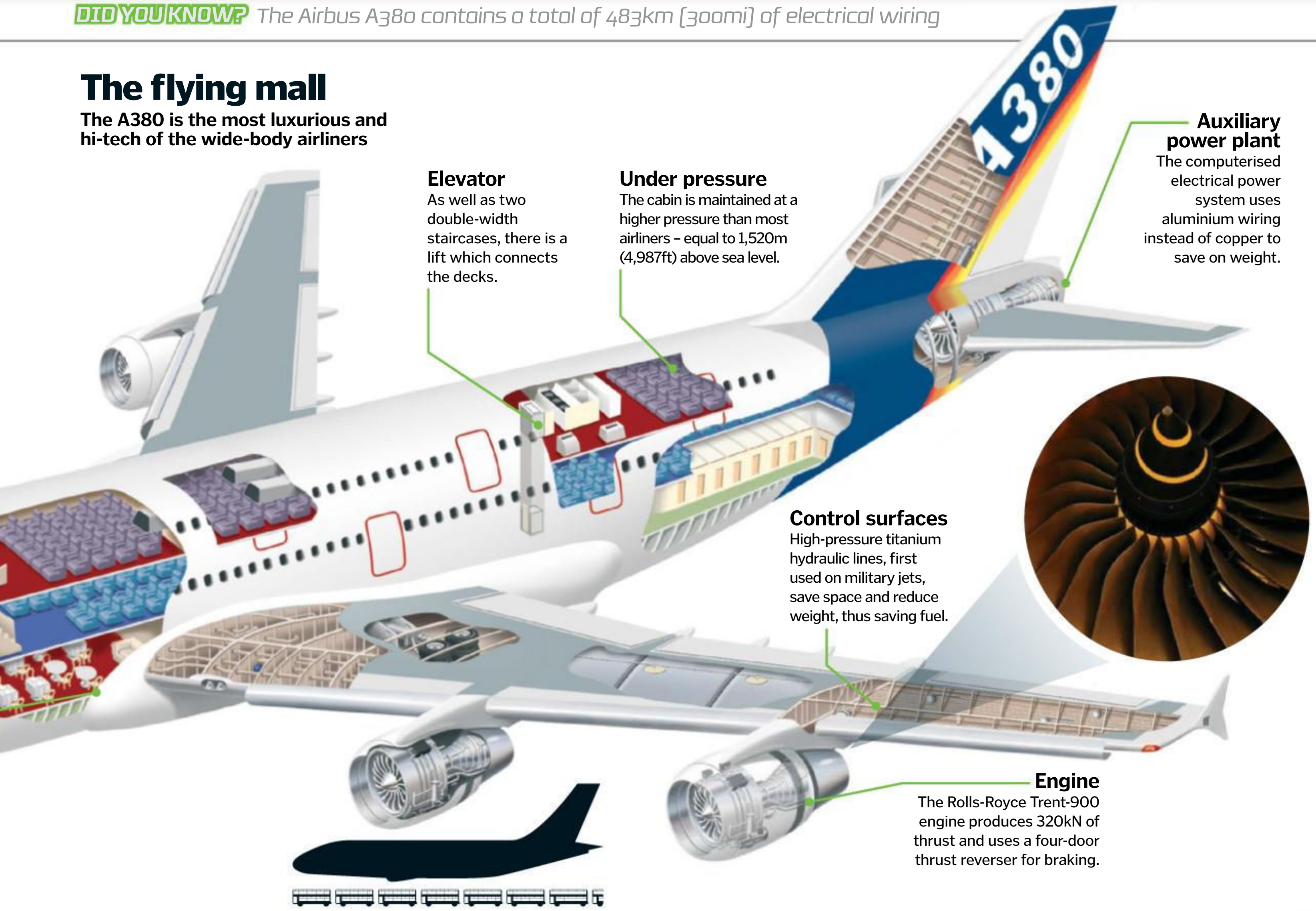
297 LARGEST FORMATION SKYDIVE

In 1996, a Mi-26 helicopter was used to set a world record for the largest freefall formation skydive from a single aircraft. The 297 skydivers jumped from 6,600 metres (21,650 feet) up.

DID YOU KNOW? *The Airbus A380 contains a total of 483km (300mi) of electrical wiring*

The flying mall

The A380 is the most luxurious and hi-tech of the wide-body airliners



Elevator
As well as two double-width staircases, there is a lift which connects the decks.

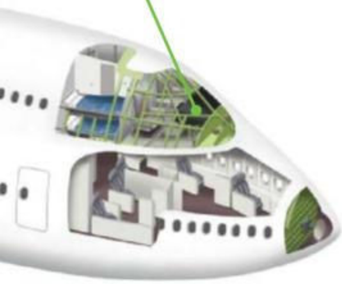
Under pressure
The cabin is maintained at a higher pressure than most airliners – equal to 1,520m (4,987ft) above sea level.

Auxiliary power plant
The computerised electrical power system uses aluminium wiring instead of copper to save on weight.

Control surfaces
High-pressure titanium hydraulic lines, first used on military jets, save space and reduce weight, thus saving fuel.

Engine
The Rolls-Royce Trent-900 engine produces 320kN of thrust and uses a four-door thrust reverser for braking.

Flight deck
The new flight management computer takes features from the 777 and includes a dedicated central maintenance computer.



Jumbo-sized construction

The components for the Airbus A380 are manufactured in plants all around Europe, but they are assembled at a huge 50-hectare (124-acre) site in Toulouse, France, in a process that takes over 1,300 employees just 11 days for each plane.

The three massive fuselage sections travel first by sea, then by barge up the Garonne River, then finally by road. Every two weeks, the road to the Airbus factory is closed overnight so the convoy can pass without holding up traffic.

The fuselage is manoeuvred using giant radio-control motorised scaffolds. The sections overlap along a 12-centimetre (4.7-inch) seam and are held together with 19,000 rivets. Once the wings and undercarriage are on, the airframe is towed to another assembly hangar for the electrical and hydraulic systems to be installed. The engines go on almost last because they are so expensive that Airbus must be sure the plane is almost ready for delivery.

An Airbus A380 being built for Thai Airways

"Airlander is much quieter and has lower carbon emissions than other aircraft"

15 Olympic swimming pools of helium

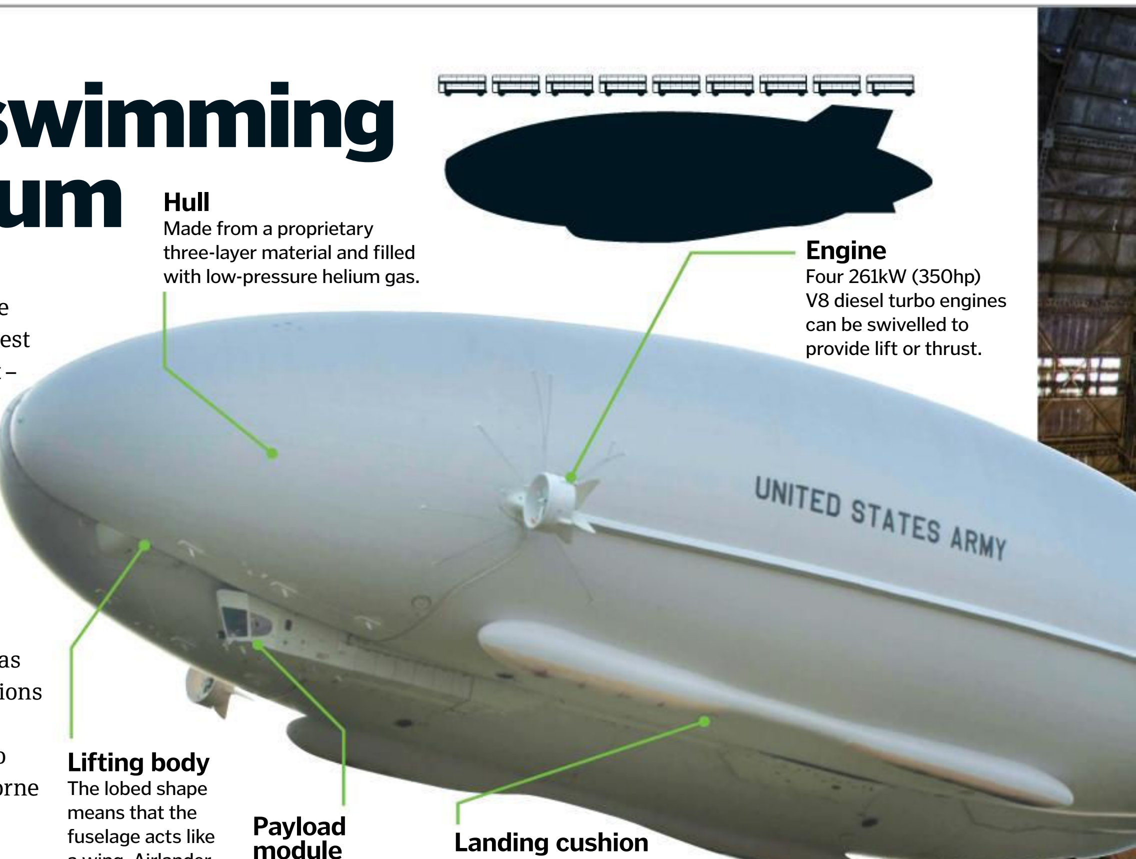
Airlander

Although it looks like a World War II zeppelin, the Airlander is a brand-new design featuring the latest technology. To date the longest aircraft ever built – and with even larger models in development – the 91.4-metre (300-foot) long hull is filled with helium to give it buoyancy. The hybrid lift system means the Airlander can take off vertically and hover, like a helicopter, yet has a range of 4,815 kilometres (3,000 miles). Airlander is much quieter and has lower carbon emissions than other aircraft carrying hefty cargo and it can stay airborne for three weeks!

The statistics…

Airlander

Length: 91.4m (300ft)
Width: 34m (111.5ft)
Height: 26m (85.3ft)
Max payload: 1,225kg (2,700lb)
Max speed: 150km/h (92mph)
Cost: £60mn ($101mn)



Hull
Made from a proprietary three-layer material and filled with low-pressure helium gas.

Engine
Four 261kW (350hp) V8 diesel turbo engines can be swivelled to provide lift or thrust.

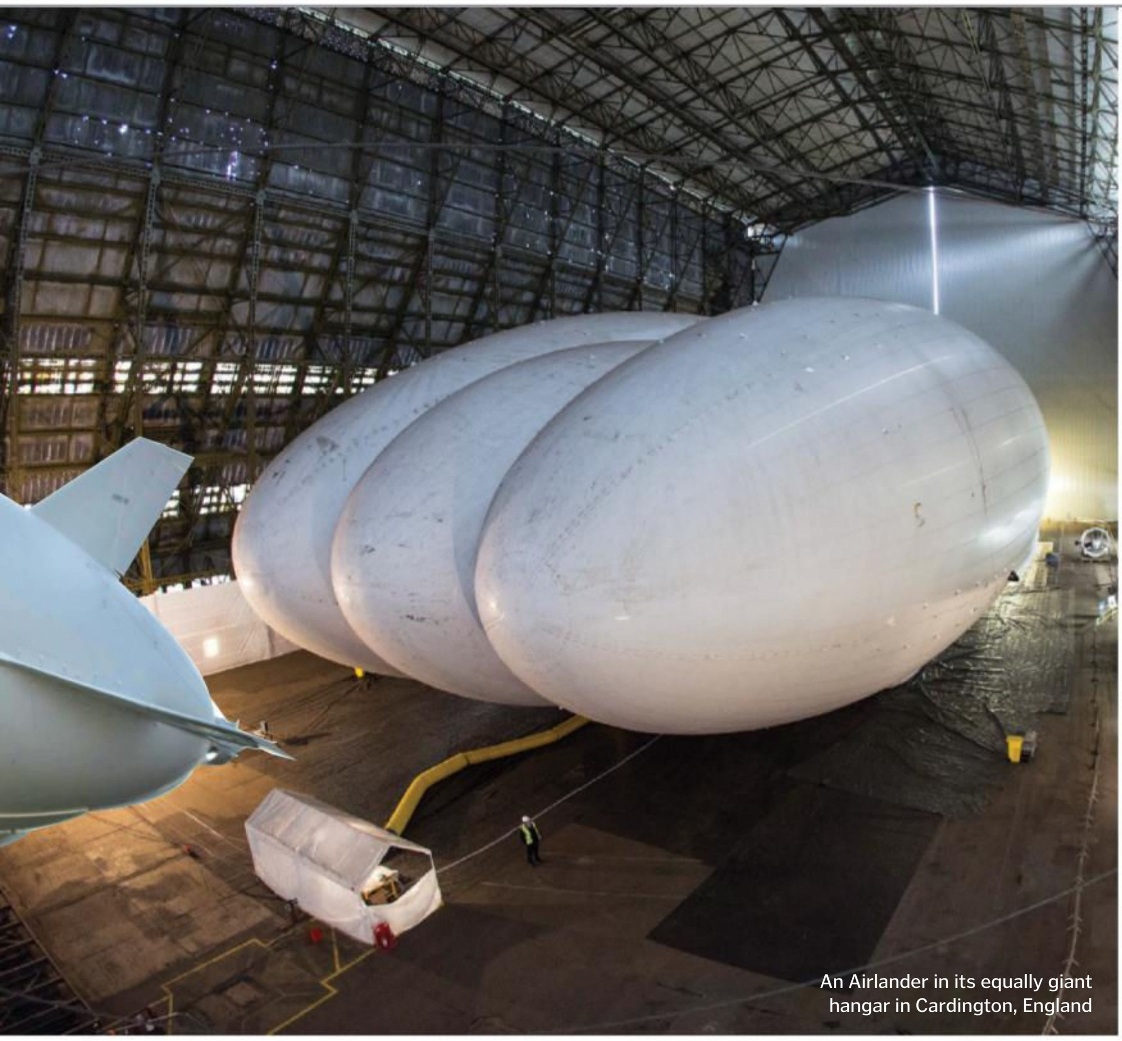
Lifting body
The lobed shape means that the fuselage acts like a wing. Airlander gains 40 per cent of its lift this way.

Payload module
Made from carbon fibre to minimise weight. The cockpit at the front needs just two crew.

Landing cushion
Instead of wheels, Airlander has inflatable tubes. Heavier versions will use a hovercraft system to touch down almost anywhere.

Буран
АН-225
387

DID YOU KNOW? *The Airlander could fly non-stop around the world without refuelling – twice!*


An Airlander in its equally giant hangar in Cardington, England

Interview
The future of airships

Chris Daniels from Hybrid Air Vehicles tells us more about the Airlander…

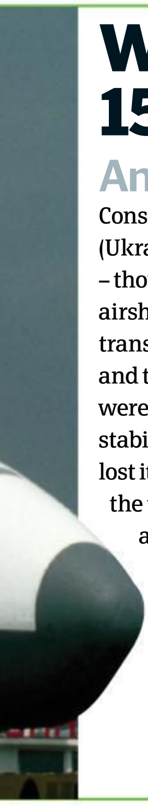
What is Airlander made from?
The hull is made from a specially constructed material that is unique to us. This is based on the materials developed for America's Cup sails and is strong, light and retains its shape. The material consists of three layers heat-welded together: a white outer layer for protection, a weave for strength and a film for helium retention. A strip a few inches wide could easily hold up a family car.

What happens if it springs a leak in flight?
There are separate compartments with valves between them. So if there is a major leak the compartment is isolated. Minor rips and tears don't have much effect as the helium is under such low pressure and there's 38,000 cubic metres (1.3 million cubic feet) of it, so it tends to seep out slowly. Tests on an old [smaller] airship showed it took over an hour and a half for an airship penetrated by 200 large-calibre bullet holes to lose enough helium to [be forced] to land.

How does Airlander cope with bad weather?
Very well. It is designed to be stable and can withstand similar weather conditions to helicopters and other aircraft. On ground, it is designed to withstand 80-knot [148-kilometre/92-mile-per-hour] winds and lightning storms, without damage. Because it's so large, it tends to ride out storms rather than get buffeted by them.

How does its cargo capacity measure up?
The biggest freight aircraft can carry over 100 tons, but they need long runways and are expensive to operate. Airlander can take off and land vertically, and even in a normal 'aeroplane' takeoff it only needs a couple of its body lengths, so it has huge advantages over aeroplanes. We expect to create a 200-ton carrying Airlander, which will be transformational for world cargo.

Could we see a return to regular transatlantic passenger trips by airship?
Airlander certainly has the capability. We feel there are opportunities in luxury travel too, opening up some extraordinary ways to do safaris (following animal migrations of caribou, wildebeest or whales) and getting to amazing locations that are otherwise difficult [to access].



Weighs the same as 157 London taxis

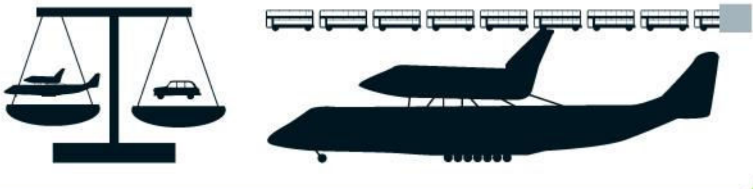
An-25 Mriya

Constructed in Ukraine in 1988, the Antonov An-225 Mriya (Ukrainian for 'dream') still holds the record of heaviest-ever plane – though its length record has now been claimed by the Airlander airship. This cargo transporter had one primary purpose – to transport the Buran space shuttle. The shuttle weighed 170 tons and the An-225 acted as its airborne launch platform. Launches were possible at heights of up to 10,000 metres (33,000 feet) and its stabilising split tail increased manoeuvrability. The An-225 Mriya lost its role after the USSR collapsed. NASA used a similar setup for the transportation of its Space Shuttles using modified Boeing 747s and rumours are circulating that the European Space Agency may be bringing it back for future space missions.

The statistics…

An-225 Mriya

Length: 84m (276ft)
Wingspan: 88.4m (290ft)
Height: 18.1m (59ft)
Weight: 285,000kg (628,317lb)
Max speed: 850km/h (528mph)
Maximum takeoff weight: 600,000kg (1.32mn lb)
Max range: 15,490km (9,625mi)



© Alex Beltyukov; Corbis; Getty; NASA; Adrian Mann/The Art Agency; Airbus SAS/P Masclet; Russian Helicopters; Boeing; Hybrid Air Vehicles; Terry Pastor

HOW IT WORKS BOOK OF AIRCRAFT

Military

32 **Aerobatic displays** The amazing tech behind the stunning aerial displays of the Red Arrows and Blue Angels

42 **100 years of fighter planes** From World War I to modern day, inside the most iconic military aircraft

50 **On board the Warthog** Why is the A-10 Thunderbolt still in use today after over four decades of flying?

52 **Supermarine Spitfire** What made the Spitfire such a spectacular aircraft in the Second World War?

54 **Lancaster bomber** Undertaking some of the most dangerous missions of WWII

56 **Sea Harrier** Dominating the subsonic jet fighter field, the Harrier changed fighter dynamics

58 **Inside a Huey** Take a look at one of the most versatile vehicles from the Vietnam War

60 **V-1 flying bomb** How the doodlebug was responsible for thousands of Allied casualties in WWII

61 **Reconnaissance drones** Unmanned aerial vehicles in the military are undertaking reconnaissance missions

62 **Sea Vixen** Delivering next-generation firepower in an all-weather jet fighter

64 **Westland Lynx** Can any other vehicle break the records held by the Westland Lynx?

66 **Strategic bombers** Take to the skies for a closer look at the dedicated bombing aircraft of war

70 **F-35 and future fighters** Meet the next-generation of stealth fighters offering all-round air supremacy

61

58

70

AEROBATIC DISPLAYS

THE AMAZING TECH BEHIND THE DEATH-DEFYING DISPLAYS

ROYAL AIR FORCE
XX227
RESCUE

DID YOU KNOW? *The Red Arrows, whose motto is "Éclat" meaning brilliance, are based at RAF Scampton in Lincolnshire*

US NAVY
US NAVY
US NAVY
US NAVY

Anyone who's seen the Red Arrows or the Blue Angels perform will know why many consider these pilots to be the world's best. They execute death-defying stunts at breakneck speeds; flying low to the ground and experiencing g-forces that makes their heads feel like 20-kilogram (44-pound) balls. They manage not only to control their aircraft, but also to work perfectly in a team, pushing themselves and their aircraft to the limit.

The Blue Angels – the US Navy's flight demonstration squadron – and Red Arrows – the UK's Royal Air Force Aerobatic Team – have very interesting origins. After World War II ended, the US chief of naval operations, Admiral Chester Nimitz, was keen to maintain the high level of public interest in naval aviation. He feared that he would lose significant amounts of funding to other areas of the US Army; therefore, he devised a plan to create a flight exhibition team. Throughout the following decades, the Blue Angels flew a number of different planes, including the F6 Hellcat, the F-4 Phantom and the A-4 Skyhawk. They finally settled on the Boeing F/A-18 Hornet in 1986, the 40th anniversary of their conception, which they still use today. The Blue Angels now perform all over America, with air shows taking place between March and November.

The Red Arrows take their name from two aerobatic display teams that preceded them, the Red Pelicans and the Black Arrows. The first Red Arrow display team was formed in 1964 after concerns that aerobatic display pilots were neglecting their combat training, as they preferred to practice their stunts. The first official Red Arrows flew the Folland Gnat which had been used by the Yellowjacks in previous years. The original team flew with seven aircraft, until 1968 when they decided to adopt their now trademarked 'Diamond Nine' formation. In 1979, the BAE Systems Hawk – a modified version of the Royal Air Force's fast jet trainer – was chosen to replace the Gnat. The Red Arrows have now performed nearly 5,000 shows and celebrated their 50th season in 2014.

© Airfix; Alamy; US Navy

Death-defying displays

Find out how display pilots pull off their incredible manoeuvres with precision and coordination

Both the Red Arrows and the Blue Angels update their show routine each year, which typically lasts between 20 and 30 minutes. They prepare three different displays and choose which one to perform by examining the weather conditions. A 'full' or 'high' show will be performed in clear weather, when the cloud base is over 1,372 metres (4,500 feet) high. This allows a full, looping display to be carried out and means that even at the top of each loop, the planes will remain visible.

If the cloud base is lower than this and conditions are overcast, a 'rolling' or 'low' display is performed. When the weather is particularly bad and the cloud base is below 762 metres (2,500 feet), a 'flat' show is performed. This will include mainly flypasts and steep turns, as these are the only manoeuvres that remain visible in such poor conditions.

The first five Red Arrow planes (Reds 1 to 5) are the front part of the overall formation, known as 'Enid.' The remaining three planes, Reds 6 to 9, make up the rear section and are known as 'Gypo.' Reds 6 and 7 are the 'Synchro Pair,' and will perform opposition manoeuvres during the second half of the show. The Blue Angels also have a similar pair – the Blue 5 and 6.

Blue Angel 5 pilot Mark Tedrow spoke about the most challenging manoeuvre that he performs: "It's called the inverted tuck over roll which is where I'm trying to hide my plane behind Blue 6, so the crowd only see one aircraft. Last year we performed this upright, but this year we decided to make things harder and perform it inverted."

Being disciplined during a manoeuvre is vital for all display pilots. Hours of practice enable the Red Arrows to move nine aircraft as one. Red 2 pilot Mike Bowden, revealed how the Red Arrows achieve this visual feat: "There's a perfect position to be in during all manoeuvres and to achieve this we aim to triangulate a position on the Team Leader's aircraft," he explains. "We use two reference points to put us in the right part of the sky, which helps us to ensure that we don't get too close. Six feet [1.8 metres] apart is close enough when you've got nine aircraft in one vicinity."

Dye in the sky

Both the Blue Angels and the Red Arrows use smoke as a visual aid for spectators, enabling them to follow a traceable path from each plane during the display. The Red Arrows are famous for their white, red and blue smoke, while the Blue Angels stick to using just white smokes.

Adding small quantities of diesel into the jet exhaust pipe produces the vapour trails. As this diesel meets the high temperatures found in the exhaust it instantly vapourises, creating a strong, visible, white smoke. The Red Arrow pilots change the smoke's colour by adding dye through switches on their control column.

Although they do add something extra to the display visually, these vapour trails have a more important function. They enable pilots to judge wind speed and direction, and make it possible for the Team Leader and Synchro Leader to see each other even when separated by large distances. They are essential to flight safety.

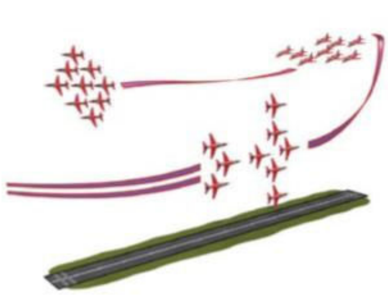
The Red Arrows can produce a vapour trail for seven minutes during a 30-minute display

DID YOU KNOW? *The Blue Angels took their name from a New York nightclub that was called The Blue Angel*

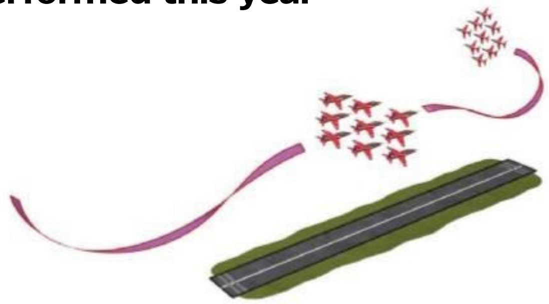
> “The first five Red Arrows planes (Reds 1 to 5) are the front part of the overall formation, known as ‘Enid’”

DISPLAY MANOEUVRES

See the display manoeuvres that will be performed this year

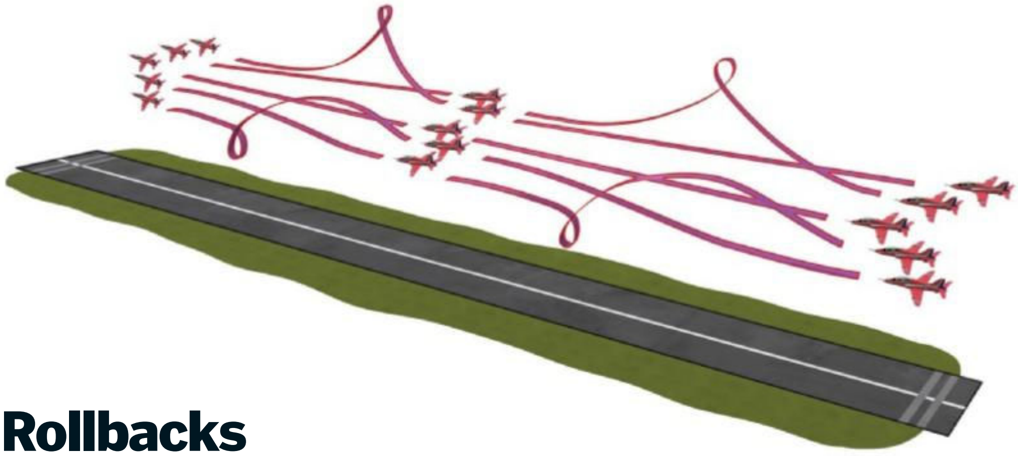


Spitfire Reversal



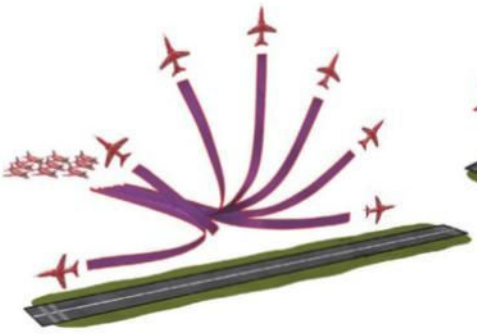
Whirlwind

The Whirlwind is a brand new manoeuvre for the 2015 Red Arrow displays and features all nine jets performing a roll followed by a Blackbird loop.



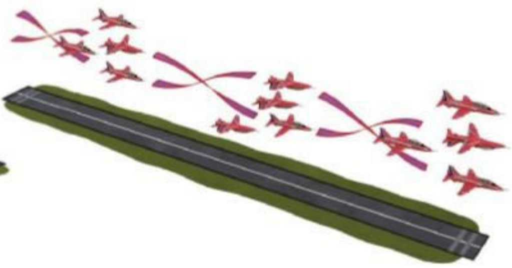
Rollbacks

Red 2 will pull out of the Diamond Nine formation and perform a full 360-degree roll around Red 4 and then himself outside of Red 4. At the same time, Red 3 will perform an identical manoeuvre around Red 5. The difficulty here is to keep the roll as tight as possible, and to time the rolls so that they are the same speed and look the same to the crowd.



Vixen Break

All planes fly directly towards the crowd, before breaking in different directions up and away from the crowd, pulling up to 7g. This is often a crowd favourite, but is one of the simplest manoeuvres to perform.



Mirror Roll

Throughout their 2015 displays, the Red Arrows will be reviving the Mirror Roll which involves Red 6 performing an inverted barrel roll at -2.5g, while Reds 7, 8 and 9 remain in formation.

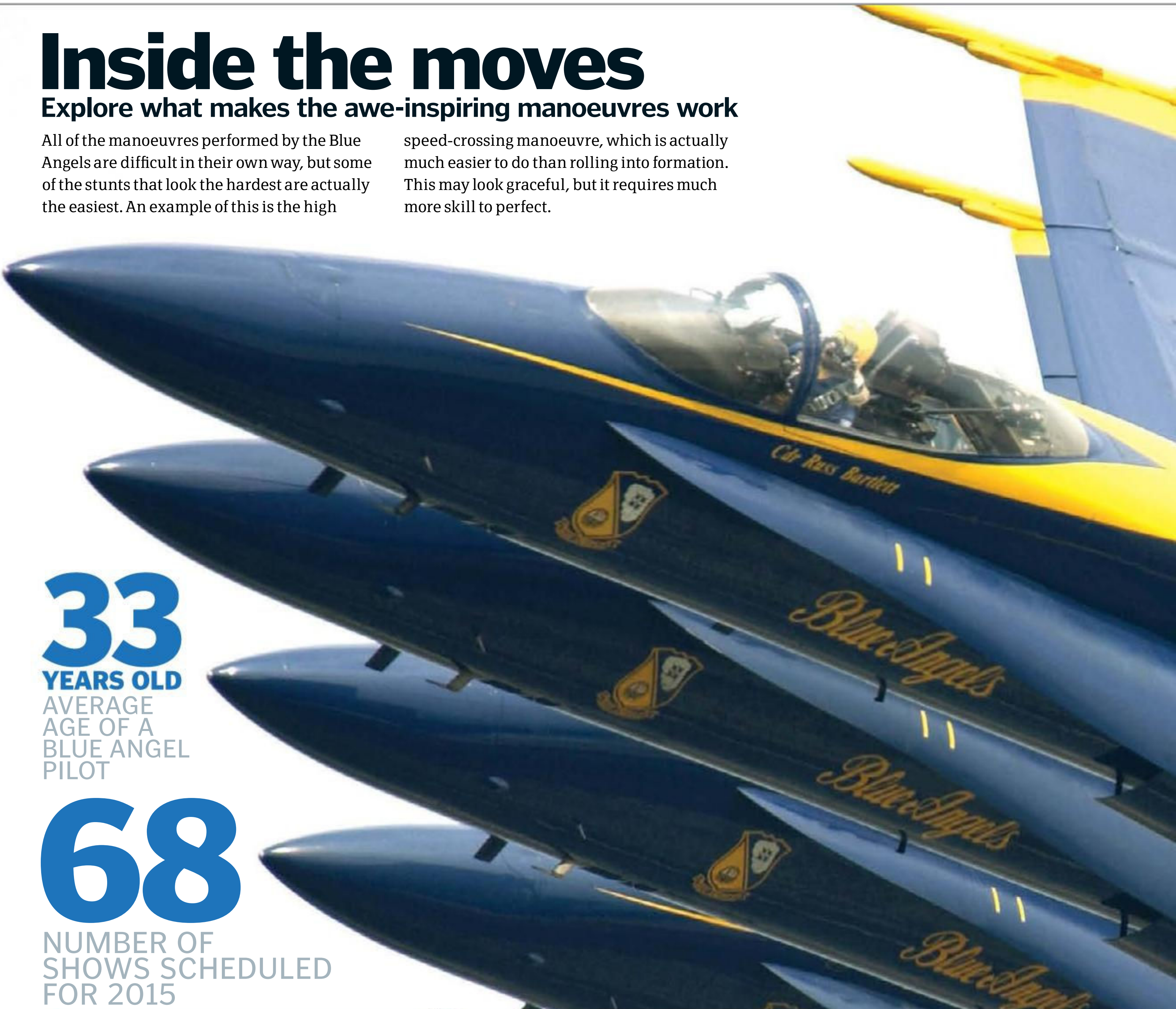
© Graham Taylor/Alamy

“The high speed-crossing manoeuvre is much easier than rolling into formation”

Inside the moves

Explore what makes the awe-inspiring manoeuvres work

All of the manoeuvres performed by the Blue Angels are difficult in their own way, but some of the stunts that look the hardest are actually the easiest. An example of this is the high speed-crossing manoeuvre, which is actually much easier to do than rolling into formation. This may look graceful, but it requires much more skill to perfect.



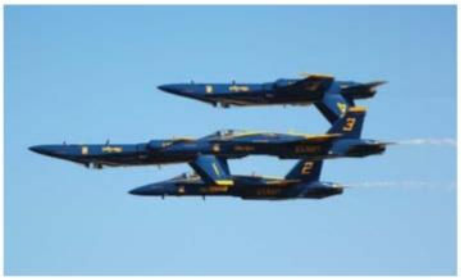
33
YEARS OLD
AVERAGE AGE OF A BLUE ANGEL PILOT

68
NUMBER OF SHOWS SCHEDULED FOR 2015

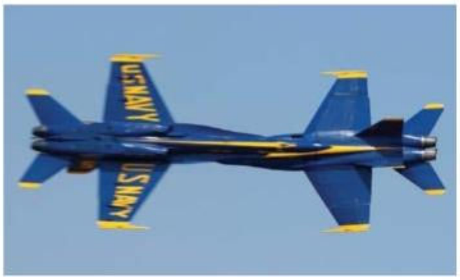
Fat Albert

Every show requires a huge behind-the-scenes effort. The Blue Angels use a C-130 Hercules to carry spare parts and support the many personnel that make their displays possible. Affectionately known as “Fat Albert”, it has a range of 3,862 kilometres (2,400 miles) and can carry a colossal 20,412-kilogram (45,000-pound) payload.

DID YOU KNOW? *The Blue Angels perform an average of 70 shows a year in over 30 different locations*

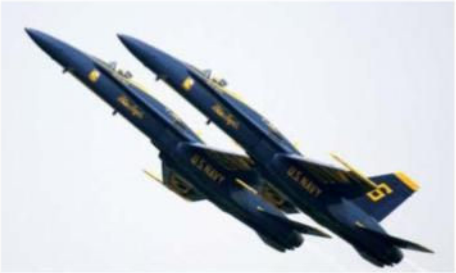


Double Farvel



Knife Edge Pass

To perform this manoeuvre, two planes fly towards the same point at high speed, before suddenly altering their position so they pass each other. This can be performed as low as 15.24 metres (50 feet).



Section High Alpha Pass

This is the slowest manoeuvre the Blue Angels perform, and involves two of the jets slowing to 193km/h (120mph) as they pitch the noses of their planes up to an angle of 45 degrees.

BOEING
F/A-18 HORNET
161967
U.S.

1200 GALLONS JET FUEL BURNT PER HOUR (4,542 LITRES)

11 MILLION SPECTATORS PER YEAR (ABOUT THE SAME AS THE POPULATION OF GREECE)

© US Navy

Blue Angels *versus* Red Arrows

Blue Angel: F/A-18 Hornet

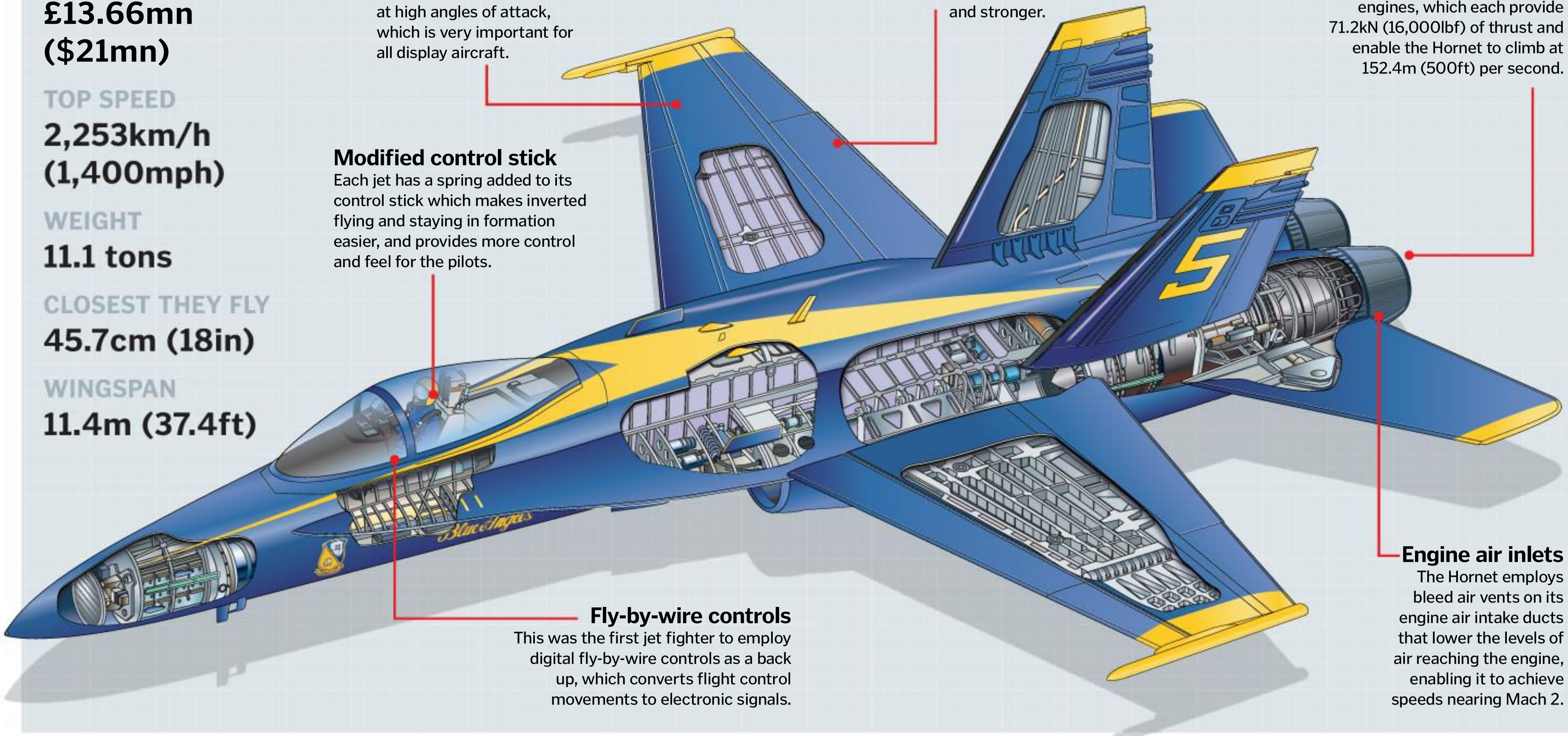
Find out about the Blue Angel F/A-18's most important features

"Efficient and reliable communications are important for the Blue Angels," says Kyetta Penn, aviation electronics technician for the Blue Angels. "It is vital that they are able to talk to each other during a display and also to the ground staff so we know what's happenings."

GPS is also absolutely vital so that their location can be pinpointed, while radar enables the pilots to see exactly what is going on around them. "They can make sure they are clear to carry out their display and that there are no other aircraft in their airspace," Penn adds.

Although every effort is made to ensure the pilot's safety, things can go wrong. Recently, part of Mark Tedrow's F/A-18 became detached mid-flight, calling into question the lifespan of these ageing fighter jets. He explains exactly what happened: "I was in a high-g rendezvous with the diamond to execute the 'the line of our swoop' manoeuvre which is when part of my wing became detached," he recalls. "This is why we take seven planes to each show; I was able to land my F/A-18, jump into the spare and complete the performance." The show must go on!

LOWEST MANOEUVRE	15.24m (50ft)
COST	£13.66mn ($21mn)
TOP SPEED	2,253km/h (1,400mph)
WEIGHT	11.1 tons
CLOSEST THEY FLY	45.7cm (18in)
WINGSPAN	11.4m (37.4ft)



Outstanding manoeuvrability
The leading-edge extensions (LEX) enable the Hornet to be controlled at high angles of attack, which is very important for all display aircraft.

Carbon fibre wings
The F/A-18 Hornet was the first aircraft to be fitted with carbon fibre wings, enabling it to be lighter and stronger.

Dual engine power
The F/A-18s are equipped with two General Electric F404-GE-400 engines, which each provide 71.2kN (16,000lbf) of thrust and enable the Hornet to climb at 152.4m (500ft) per second.

Modified control stick
Each jet has a spring added to its control stick which makes inverted flying and staying in formation easier, and provides more control and feel for the pilots.

Fly-by-wire controls
This was the first jet fighter to employ digital fly-by-wire controls as a back up, which converts flight control movements to electronic signals.

Engine air inlets
The Hornet employs bleed air vents on its engine air intake ducts that lower the levels of air reaching the engine, enabling it to achieve speeds nearing Mach 2.

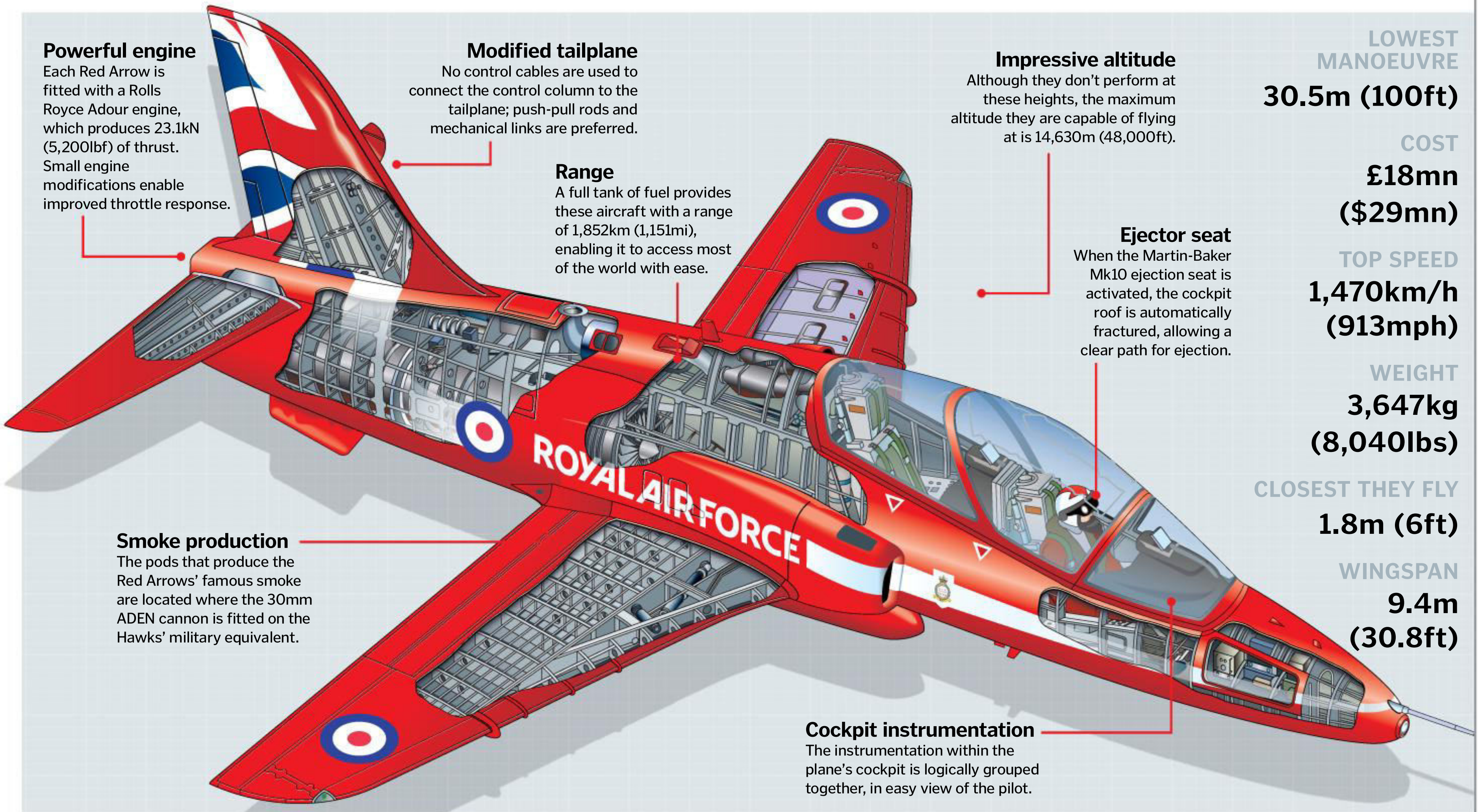
DID YOU KNOW? *The front five Red Arrows are known as "Enid," after Enid Blyton's Famous Five*

Red Arrow: Hawk T1

Why the Hawk is still the best choice for displays

The Hawk T1 has been used by the Red Arrows since 1979 and Red 2 pilot Flt Lt Mike Bowden tells us why: "The Hawk is used by the military to train their pilots and the Red Arrows. Hawk is ultimately the same aircraft bar a few modifications," he says. "Although it is somewhat dated, the Hawk is absolutely perfect for what we do. It handles well, especially well in formation, and doesn't have any fancy gadgetry that could go wrong and cause unnecessary problems, which is very important considering how many shows we perform and the precision flying we need to execute."

The Hawk was designed to be easily fixed with the majority of its physical parts interchangeable for convenience – ideal for the Red Arrows who often perform on consecutive days. Maintenance is performed under very strict controls and all procedures are thoroughly supervised and checked to ensure the jets are safe to fly.



Powerful engine
Each Red Arrow is fitted with a Rolls Royce Adour engine, which produces 23.1kN (5,200lbf) of thrust. Small engine modifications enable improved throttle response.

Modified tailplane
No control cables are used to connect the control column to the tailplane; push-pull rods and mechanical links are preferred.

Range
A full tank of fuel provides these aircraft with a range of 1,852km (1,151mi), enabling it to access most of the world with ease.

Impressive altitude
Although they don't perform at these heights, the maximum altitude they are capable of flying at is 14,630m (48,000ft).

Ejector seat
When the Martin-Baker Mk10 ejection seat is activated, the cockpit roof is automatically fractured, allowing a clear path for ejection.

Smoke production
The pods that produce the Red Arrows' famous smoke are located where the 30mm ADEN cannon is fitted on the Hawks' military equivalent.

Cockpit instrumentation
The instrumentation within the plane's cockpit is logically grouped together, in easy view of the pilot.

LOWEST MANOEUVRE
30.5m (100ft)

COST
£18mn ($29mn)

TOP SPEED
1,470km/h (913mph)

WEIGHT
3,647kg (8,040lbs)

CLOSEST THEY FLY
1.8m (6ft)

WINGSPAN
9.4m (30.8ft)

GROUND CREW:

Aircraft engineers
Responsible for all the upkeep and maintenance on the jets, these engineers are present at all displays, ensuring that everything is functioning properly.

Flight operations
This team is responsible for all aviation planning and coordination, ensuring that the daily schedule can be carried out without delay.

Team manager
Head of the administration team, the team manager oversees all aspects of organising the team; from booking accommodation to organising leave passes.

Images by Ian Moore

STAYING SAFE IN THE SKY

A number of steps are taken to keep aerobatic display pilots in one piece

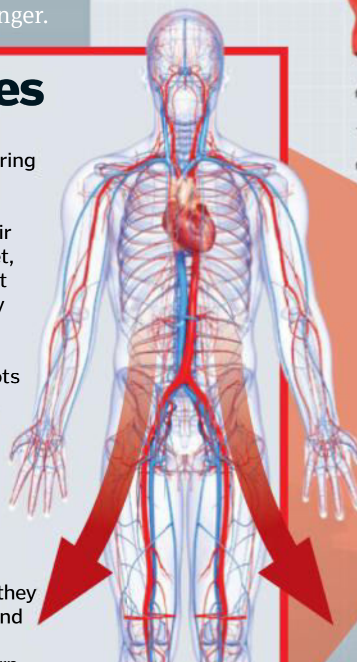
The purpose of the Red Arrows and the Blue Angels is to thrill millions of spectators every year, but they never compromise on pilot safety. Due to the nature of their flying and the high number of shows they perform, accidents do happen, although they are less regular than they were when the aerobatic teams first performed. By studying both the pilots and the planes themselves, both teams are now aware of exactly how far man and machine can be pushed. Both the Blue Angel and the Red Arrow pilots wear specific safety equipment which enables them to perform their amazing displays with the minimum amount of danger.

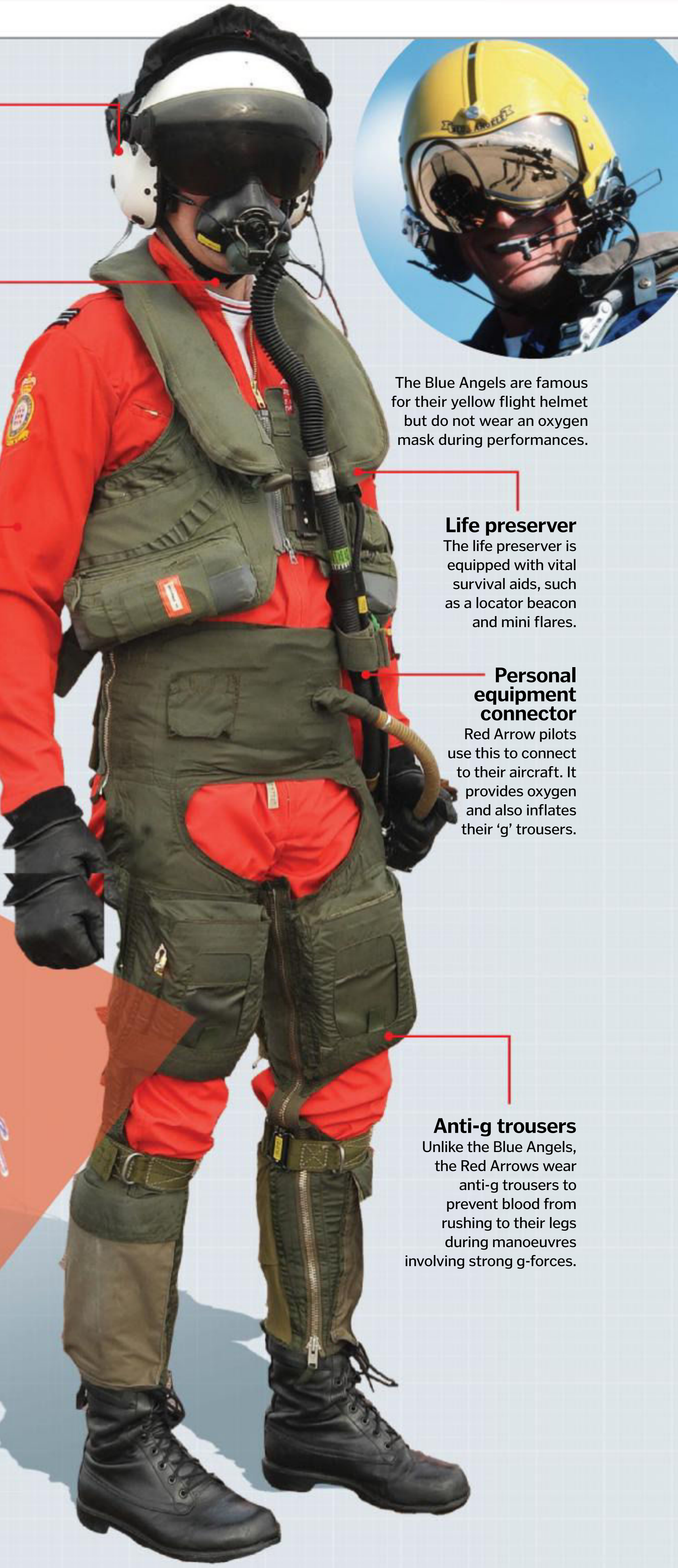
Combating g-forces

We measure gravity in terms of how much acceleration a force applies to an object. During some of their daring manoeuvres, aerobatic pilots will often be exposed to extreme gravitational forces. These forces direct their blood away from the brain towards their feet, causing the heart to stop pumping sufficient blood back to the brain which will eventually cause the pilot to totally blackout.

There are two ways that aerobatic pilots can counteract this problem. Red Arrow pilots wear a g-suit which employs a compressed air and bladder system. This compresses the legs and abdomen, reducing the likelihood of a blackout by reducing the amount of blood able to flow away from the brain.

Blue Angel pilots undergo specific training to enable them to fly without g-suits. This is because it is impossible to wear them when they fly, as they rest their forearms on their legs and use their knees as a fulcrum which the suits could interfere with if worn. Instead, they learn to tense their lower body muscles and exhale sharply (known as the 'hick' manoeuvre), that slows the rate at which the blood flows away from the brain. Blue Angel pilots are mandated to exercise at least six times a week, which keeps them fit and helps their bodies cope with g-force. On top of this, they train in a centrifuge each year which exposes them to extreme g-force and lets them practice dealing with its effects.





Flying helmet
Although it primarily functions to protect the pilot's head, the helmet houses the communications equipment as well.

Oxygen mask
The Red Arrow pilots all wear oxygen masks fitted with a microphone, but their Blue Angel counterparts do not, as they typically don't fly above 4,572m (15,000ft).

Display flying suit
The Red Arrows and the Blue Angels have their own display suits accordingly coloured to suit their name. These are not worn during training.

The Blue Angels are famous for their yellow flight helmet but do not wear an oxygen mask during performances.

Life preserver
The life preserver is equipped with vital survival aids, such as a locator beacon and mini flares.

Personal equipment connector
Red Arrow pilots use this to connect to their aircraft. It provides oxygen and also inflates their 'g' trousers.

Anti-g trousers
Unlike the Blue Angels, the Red Arrows wear anti-g trousers to prevent blood from rushing to their legs during manoeuvres involving strong g-forces.

DID YOU KNOW? *The Blue Angel jets can be made combat ready in less than 72 hours*

What it takes to be a display pilot

Learn about the rigorous interview and training that future pilots have to face

The interview process for selecting a new member of a display team is incredibly thorough. In the case of the Blue Angels, there has to be a completely unanimous (16-0) vote in favour of a candidate in order for them to join.

The Red Arrows will shortlist nine potential pilots via a pre-selection board, who are then invited for the seven-day interview. During this time, the candidates will undertake a flying test, meet the current team, accompany a Red Arrow pilot during a display practice and be formally interviewed. Once this has been completed, the current team will meet to decide which applicants have been successful.

Flight lieutenant Mike Bowden, who pilots Red 2, explains how first-timers learn to fly in unison: "When you fly in formation on the front line, you wait for the aircraft around you to move and copy what they do," he says. "If we were to do this in the Red Arrows it would make the overall formation look very broken, which is why we learn to follow voice commands from the Team Leader). We aim to perfect formation flying before moving to complex manoeuvres."

After meeting the initial criteria, Blue Angel applicants, or 'rushees' as they're fondly referred to, shadow the current pilots for numerous displays. They watch everything the existing team do, attend team briefs and go to social engagements. Candidates are then whittled down, with the remaining potential pilots put forward for a daunting one versus 16 interview, where all current Blue Angel pilots and officers ask the candidate a question.

After this, the current team sits down and decides which candidates will be joining the following year's team. We spoke to LCDR Mark Tedrow, the lead solo pilot for the Blue Angels, who revealed how they train: "The Blue Angels are so unique and the flying we do is very different to anything you do in the military – it really does feel like learning to fly all over again," he says. "Between the end of one season and the start of the next, we aim to accumulate 120 training flights. We are usually flying 15 times per week, which is a fairly gruelling schedule, but that means we can perform our manoeuvres practically from muscle memory."

Blue Angels recruits have to complete a variety of survival challenges before earning their qualifications to fly with the team

The experience you'll need to qualify

With only three spots available each year, gaining a place in a display team needs a very specific set of skills

RED ARROWS

Education

Many pilots are educated to degree level, but this isn't a requirement.

Experience

- ☑ Completed a frontline tour of duty.
- ☑ Assessed as being above average in their flying role.
- ☑ An exceptional flying record that includes reports on operational flights.

Flying Hours

A MINIMUM OF

1,500

HOURS IS EXPECTED.

Becoming Team Leader

To apply to become Team Leader, or the 'Boss', a pilot must have completed a three-year tour with the Red Arrows earlier in their career, which makes the number of people that can apply for this role limited. The Royal Air Force personnel department will select the officer they believe is best suited to carry out the wide range of duties expected of a Team Leader.

BLUE ANGEL'S

Education

Many pilots are educated to degree level, but this isn't a requirement

Experience

- ☑ Experience in an F/A-18.
- ☑ Carrier-qualified, active-duty Navy or Marine Corps tactical jet pilot.
- ☑ Combat experience, usually in landing on and taking off from aircraft carriers.

Flying Hours

A MINIMUM OF

1,250

FLYING HOURS IS EXPECTED.

Becoming 'The Boss'

The Chief of Naval Air Training selects the 'Boss', the Blue Angels commanding officer. The Boss must have at least 3,000 tactical jet flight-hours and have also commanded a tactical jet squadron. The Commanding Officer flies the Number 1 jet and leads all of the formations.

© MOD/Crown; Thinkstock; Corbis

1938
Supermarine Spitfire
The Supermarine Spitfire was used by the RAF and other Allied forces during WWII. It was designed as a short-range, high-performance interceptor aircraft, with a maximum speed of 595km/h (370mph). Originally fitted with eight .303 Browning machine guns, it helped defend Britain's coastline during the Battle of Britain.

1989
Harrier II
Introduced to active service in December 1989, the Harrier II is an example of a vertical and/or short-takeoff and landing (V/STOL) jet aircraft, perfect for use on aircraft carriers. It was frequently used in combat during missions in Kosovo, Iraq and Afghanistan.

1983
F-117 Nighthawk
The F-117 Nighthawk was equipped with pioneering stealth technology and was designed to have a minimal radar cross-section, making it very hard to detect by traditional monostatic radars. During its 25 years of service, only one was ever lost in combat.

CELEBRATING FIGHTER

FROM WWI TO MODERN DAY, INSIDE THE MOST ICONIC MILITARY AIRCRAFT

From daring dogfights over World War I France, to the computer-powered prowess of the modern era's jet fighters, the history of aerial warfare is nearly as old as flight itself.

In 1915, Dutch engineer Anton Fokker devised an interrupter gear, a simple mechanism that allowed a fixed machine gun to fire through a plane's running propeller blades. The first plane to use this was the Fokker Eindecker, which was so effective it began what the British Royal Flying Corps referred to as the 'Fokker Scourge'. This sparked an international race to create faster, more manoeuvrable and ever-more destructive aircraft.

By the end of the Great War, the tactical advantages of maintaining air superiority were well established and by 1939 and the dawn of the Second World War, another leap in aerial combat was already dominating the skies. Capable of hitting speeds of over 500 kilometres (311 miles) per hour, the Messerschmitt Bf 109 was over three times faster than the Eindecker. From its testing ground in the skies of the Spanish Civil War to the

DID YOU KNOW? *Frenchman Adolphe Pégoud was named the first flying ace of WWI after shooting down five German aircraft*

1916
Sopwith Pup

Equipped with a rotary engine and weighing only 357kg (787lb), it had a range of over 300km (186mi). It was armed with only a single Vickers machine gun and has a fabric-covered, wooden framework. It was nicknamed the 'Pup' as it was smaller than the two-seat Sopwith 1.5 Strutter.

1949
F-86 Sabre

First used in 1949, the F-86 Sabre was used by more than 20 different nations prior to its eventual retirement in 1994. An example of a swept-wing, transonic jet fighter aircraft, it also featured a 'flying tail', which gave it superb manoeuvrability at altitude.

2005
Lockheed Martin F-22 Raptor

The F-22 Raptor is the leading stealth tactical fighter aircraft. Its F-119 engines are regarded as the most advanced ever produced. Pilots benefit from 360-degree awareness when flying. Their ability to super-cruise at Mach 1.5 without afterburners makes them particularly lethal.

100 YEARS OF PLANES

invasions of Poland and France, this powerful, lightweight and well-armed fighter set a new precedent for fighter planes.

Aerial warfare was now recognised as the key to strategic success on the ground. Luckily, Allied machines, such as the Rolls Royce-powered Spitfire that was already in service at the outbreak of the war, were able to out-class their German rivals. In the final months of the war, however, the future of fighter aircraft had already taken to the skies. Though it came too late and in too small a number to turn the tide of the war for Hitler, the Messerschmitt Me 262 was the first-ever jet fighter, capable of speeds of 870 kilometres (541 miles) per hour.

Some of the last propeller-powered combat was seen in the Korean War of 1950 to '53, before the world fully entered into the jet age. The skies of the Cold War became tensely patrolled by Soviet MiG-15s, American F-15 fighters and some of the fastest planes ever engineered. Then specialist vertical takeoff and landing (VTOL) aircraft were developed for deployments on aircraft carriers, while secret stealth and surveillance technology was covertly advanced to wage the war in the shadows.

In modern warfare the job of the fighter plane is still a crucial element. The new generation of computer-assisted jets are capable of more roles and simultaneous operations than ever before; reducing the risk to the pilot, increasing the threat to the enemy and ensuring complete dominance of the skies.

© Alamy; Thinkstock; Rex Features; EuroFighter/ Geoffrey Lee

Modern-day tech

How the new generations of military tech changed the face of aerial warfare

Ever since the Messerschmitt Me 262, nicknamed the Swallow, first took flight in World War II, the jet age has seen fighter-plane technology soar. One key difference between the fighters of today and their ancestors is the need for flexibility. While warplanes were previously designed for specific tasks – such as fighter bombers, escort, or reconnaissance – today's aircraft are expected to perform a range of roles, even simultaneously. For example, the Eurofighter Typhoon carries over a dozen brackets under its fuselage. This enables it to carry any combination of air-to-air or ground-attack armament, or extra fuel pods for prolonged sorties, fulfilling the potential for every combat role.

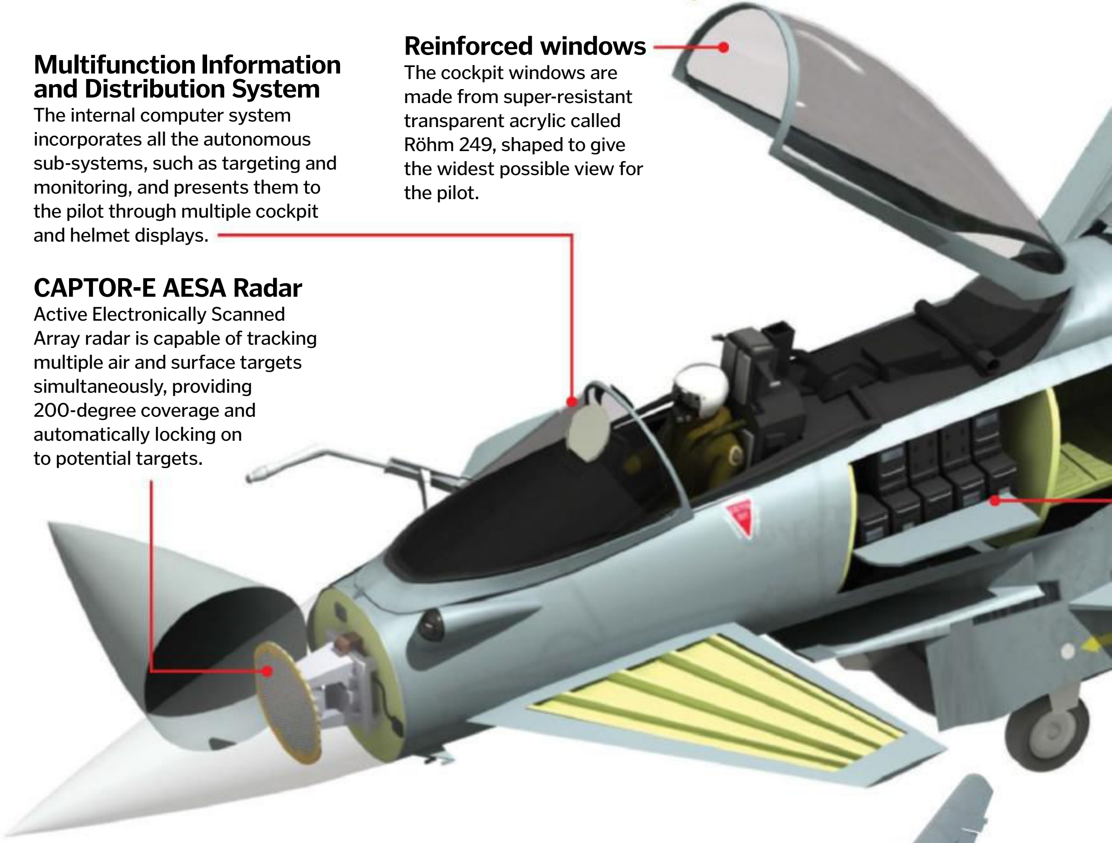
With machines becoming ever faster and weapons systems leaving little to no room for error, even the lightning reactions of the hardiest flying maverick would struggle to last five minutes of air combat – that is, without the aid of computer technology. Though it goes without saying the role of a pilot still demands incredible levels of skill, endurance, multitasking and quick reactions under pressure, the onboard computer is now an essential component of any fighter plane.

The heads-up display (HUD), iconic from films such as *Top Gun*, was among the most important electronic upgrades to the cockpits of fighter jets. It relays target tracking, sensor, navigation and other data direct to the pilot. The HUD computer is connected to all the external and internal sensors of the aircraft, so it's able to collate, prioritise and even give guidance based on this data. This has enabled pilots to quickly engage various threats, enact countermeasures and even land safely, all while keeping two eyes firmly focused on the danger zone.

Though within the last few decades fighter technology has leapt several generations, in step with the growing capabilities of computers, the principles of assisting pilot operation have remained the same. For example, the Human Machine Interface (HMI) and Flight Control System (FCS) of the Eurofighter accommodates voice input/output controls, Autopilot, Autothrottle and Flight Director Modes, all to assist handling. In addition, its latest generation of radar is able to identify and prioritise threats. With all this, it's no wonder fighter pilots still feel a special bond with these incredible machines.

Typhoon Tranche 3 Eurofighter

The technology inside Europe's £100 million fighter will take your breath away

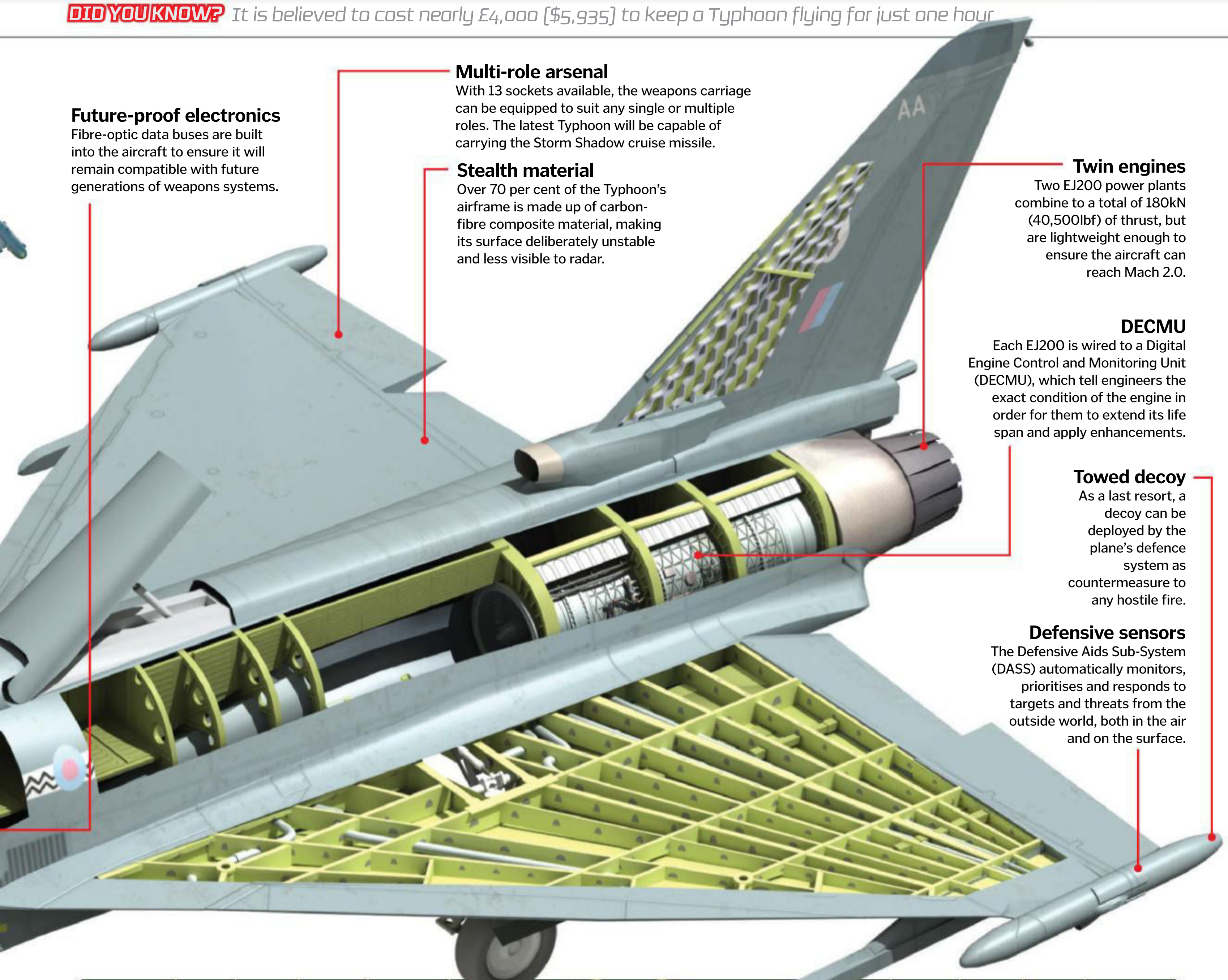


Multifunction Information and Distribution System
The internal computer system incorporates all the autonomous sub-systems, such as targeting and monitoring, and presents them to the pilot through multiple cockpit and helmet displays.

Reinforced windows
The cockpit windows are made from super-resistant transparent acrylic called Röhm 249, shaped to give the widest possible view for the pilot.

CAPTOR-E AESA Radar
Active Electronically Scanned Array radar is capable of tracking multiple air and surface targets simultaneously, providing 200-degree coverage and automatically locking on to potential targets.

DID YOU KNOW? *It is believed to cost nearly £4,000 ($5,935) to keep a Typhoon flying for just one hour*



Future-proof electronics
Fibre-optic data buses are built into the aircraft to ensure it will remain compatible with future generations of weapons systems.

Multi-role arsenal
With 13 sockets available, the weapons carriage can be equipped to suit any single or multiple roles. The latest Typhoon will be capable of carrying the Storm Shadow cruise missile.

Stealth material
Over 70 per cent of the Typhoon's airframe is made up of carbon-fibre composite material, making its surface deliberately unstable and less visible to radar.

Twin engines
Two EJ200 power plants combine to a total of 180kN (40,500lbf) of thrust, but are lightweight enough to ensure the aircraft can reach Mach 2.0.

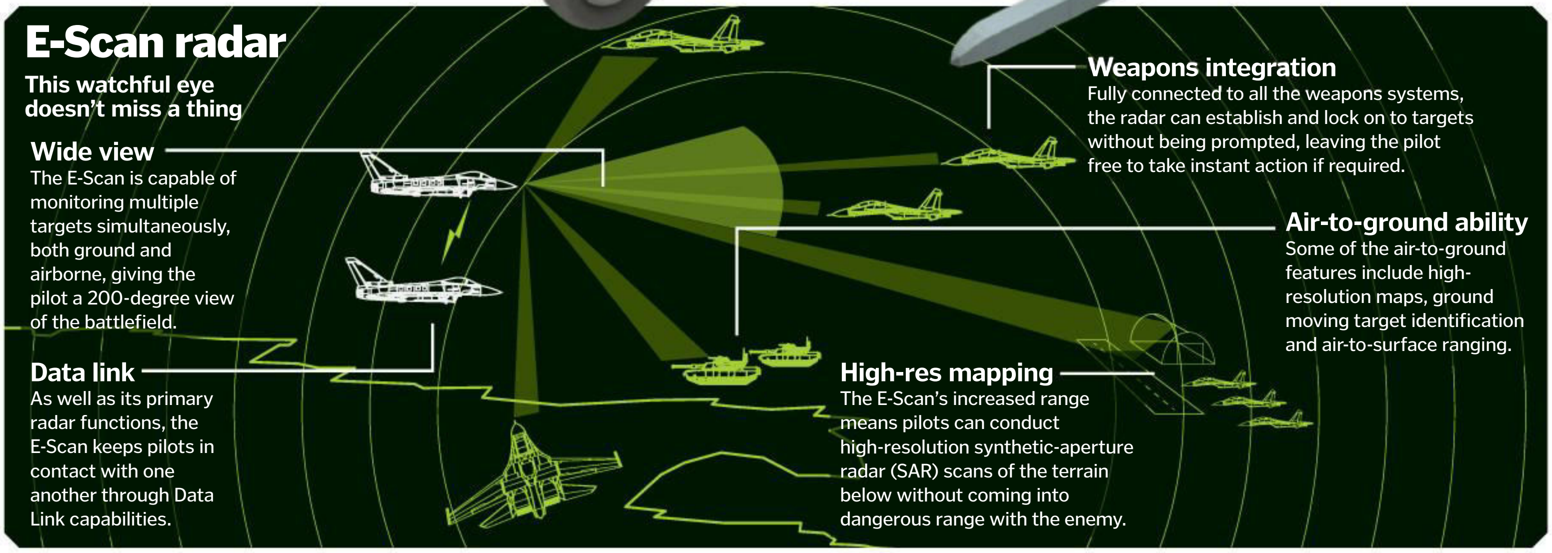
DECMU
Each EJ200 is wired to a Digital Engine Control and Monitoring Unit (DECMU), which tell engineers the exact condition of the engine in order for them to extend its life span and apply enhancements.

Towed decoy
As a last resort, a decoy can be deployed by the plane's defence system as countermeasure to any hostile fire.

Defensive sensors
The Defensive Aids Sub-System (DASS) automatically monitors, prioritises and responds to targets and threats from the outside world, both in the air and on the surface.

E-Scan radar

This watchful eye doesn't miss a thing



Wide view
The E-Scan is capable of monitoring multiple targets simultaneously, both ground and airborne, giving the pilot a 200-degree view of the battlefield.

Data link
As well as its primary radar functions, the E-Scan keeps pilots in contact with one another through Data Link capabilities.

Weapons integration
Fully connected to all the weapons systems, the radar can establish and lock on to targets without being prompted, leaving the pilot free to take instant action if required.

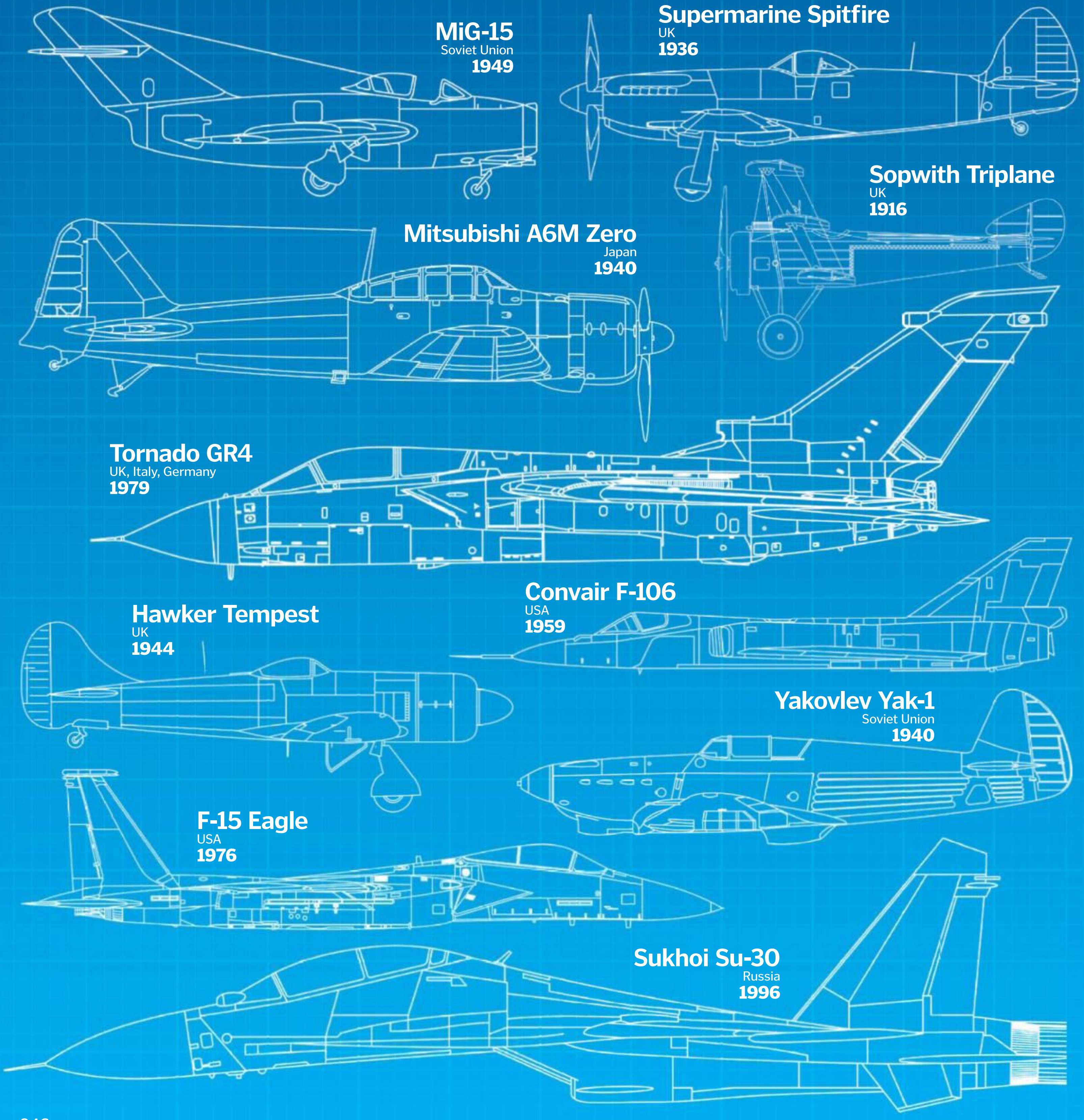
Air-to-ground ability
Some of the air-to-ground features include high-resolution maps, ground moving target identification and air-to-surface ranging.

High-res mapping
The E-Scan's increased range means pilots can conduct high-resolution synthetic-aperture radar (SAR) scans of the terrain below without coming into dangerous range with the enemy.

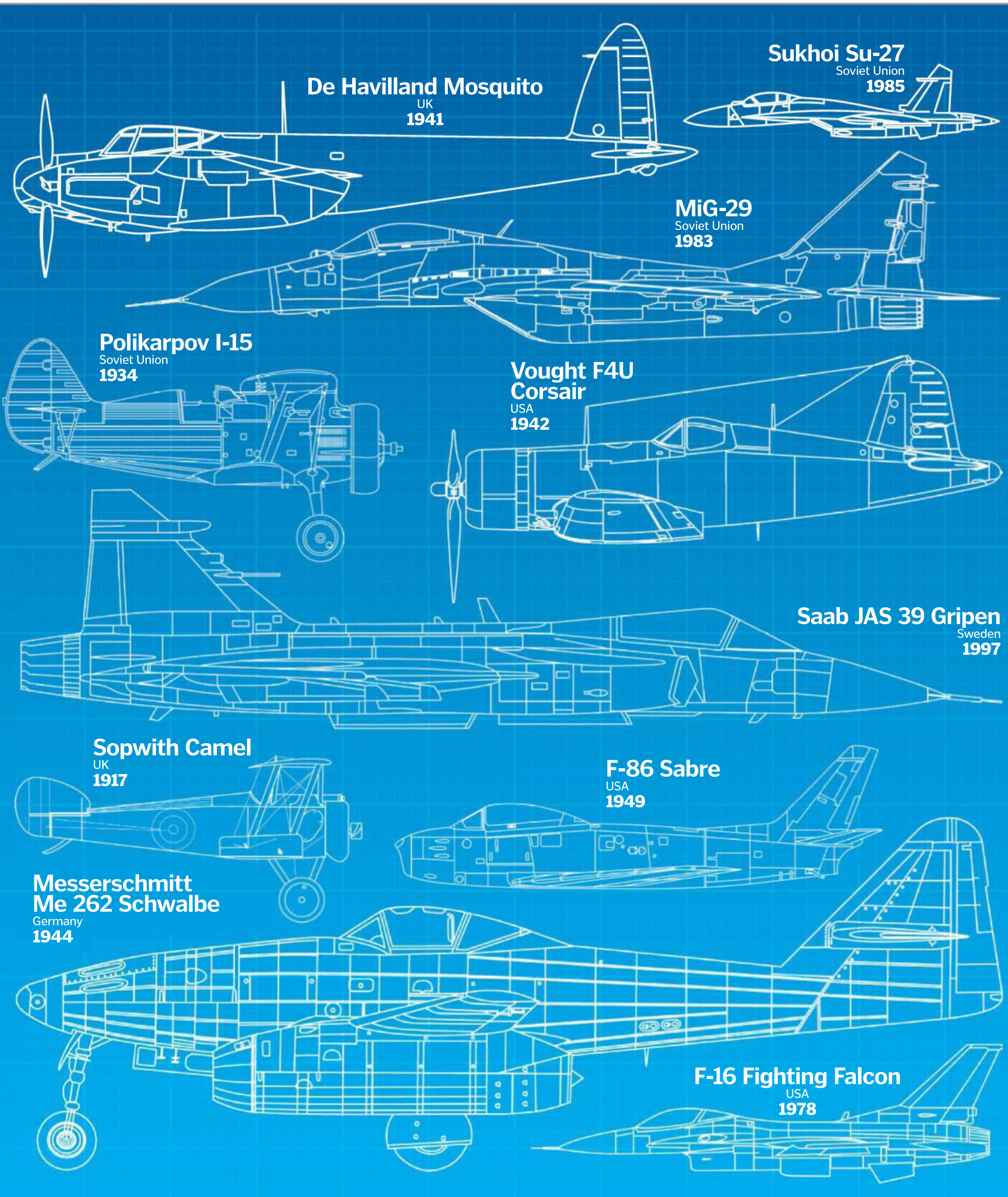
© EuroFighter/ Markus Zinner

AVIATION HISTORY

Discover how warplanes have developed through the ages


MiG-15
Soviet Union
1949
Supermarine Spitfire
UK
1936
Sopwith Triplane
UK
1916
Mitsubishi A6M Zero
Japan
1940
Tornado GR4
UK, Italy, Germany
1979
Hawker Tempest
UK
1944
Convair F-106
USA
1959
Yakovlev Yak-1
Soviet Union
1940
F-15 Eagle
USA
1976
Sukhoi Su-30
Russia
1996

DID YOU KNOW? *The F-100 Super Sabre was the first-ever US fighter plane to achieve supersonic speeds*


De Havilland Mosquito
UK
1941
Sukhoi Su-27
Soviet Union
1985
MiG-29
Soviet Union
1983
Polikarpov I-15
Soviet Union
1934
Vought F4U Corsair
USA
1942
Saab JAS 39 Gripen
Sweden
1997
Sopwith Camel
UK
1917
F-86 Sabre
USA
1949
Messerschmitt Me 262 Schwalbe
Germany
1944
F-16 Fighting Falcon
USA
1978

Evolution of the fighter plane

How the old war dogs of the skies reached new heights in their time

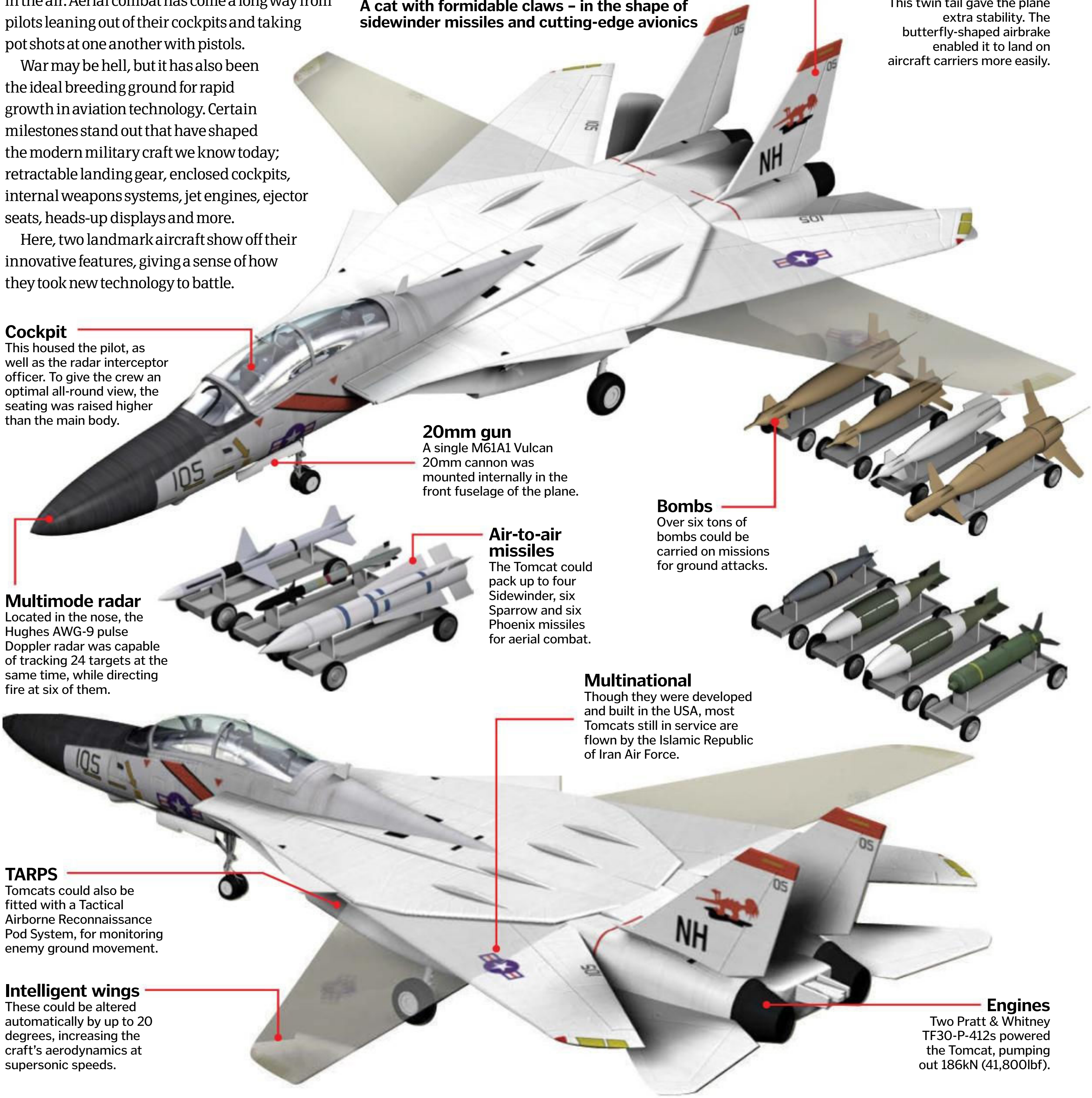
Almost as soon as we were able to fly, we have been inventing new ways to destroy one another in the air. Aerial combat has come a long way from pilots leaning out of their cockpits and taking pot shots at one another with pistols.

War may be hell, but it has also been the ideal breeding ground for rapid growth in aviation technology. Certain milestones stand out that have shaped the modern military craft we know today; retractable landing gear, enclosed cockpits, internal weapons systems, jet engines, ejector seats, heads-up displays and more.

Here, two landmark aircraft show off their innovative features, giving a sense of how they took new technology to battle.

Grumman F-14A Tomcat

A cat with formidable claws – in the shape of sidewinder missiles and cutting-edge avionics



Tail
This twin tail gave the plane extra stability. The butterfly-shaped airbrake enabled it to land on aircraft carriers more easily.

Cockpit
This housed the pilot, as well as the radar interceptor officer. To give the crew an optimal all-round view, the seating was raised higher than the main body.

20mm gun
A single M61A1 Vulcan 20mm cannon was mounted internally in the front fuselage of the plane.

Bombs
Over six tons of bombs could be carried on missions for ground attacks.

Air-to-air missiles
The Tomcat could pack up to four Sidewinder, six Sparrow and six Phoenix missiles for aerial combat.

Multimode radar
Located in the nose, the Hughes AWG-9 pulse Doppler radar was capable of tracking 24 targets at the same time, while directing fire at six of them.

Multinational
Though they were developed and built in the USA, most Tomcats still in service are flown by the Islamic Republic of Iran Air Force.

TARPS
Tomcats could also be fitted with a Tactical Airborne Reconnaissance Pod System, for monitoring enemy ground movement.

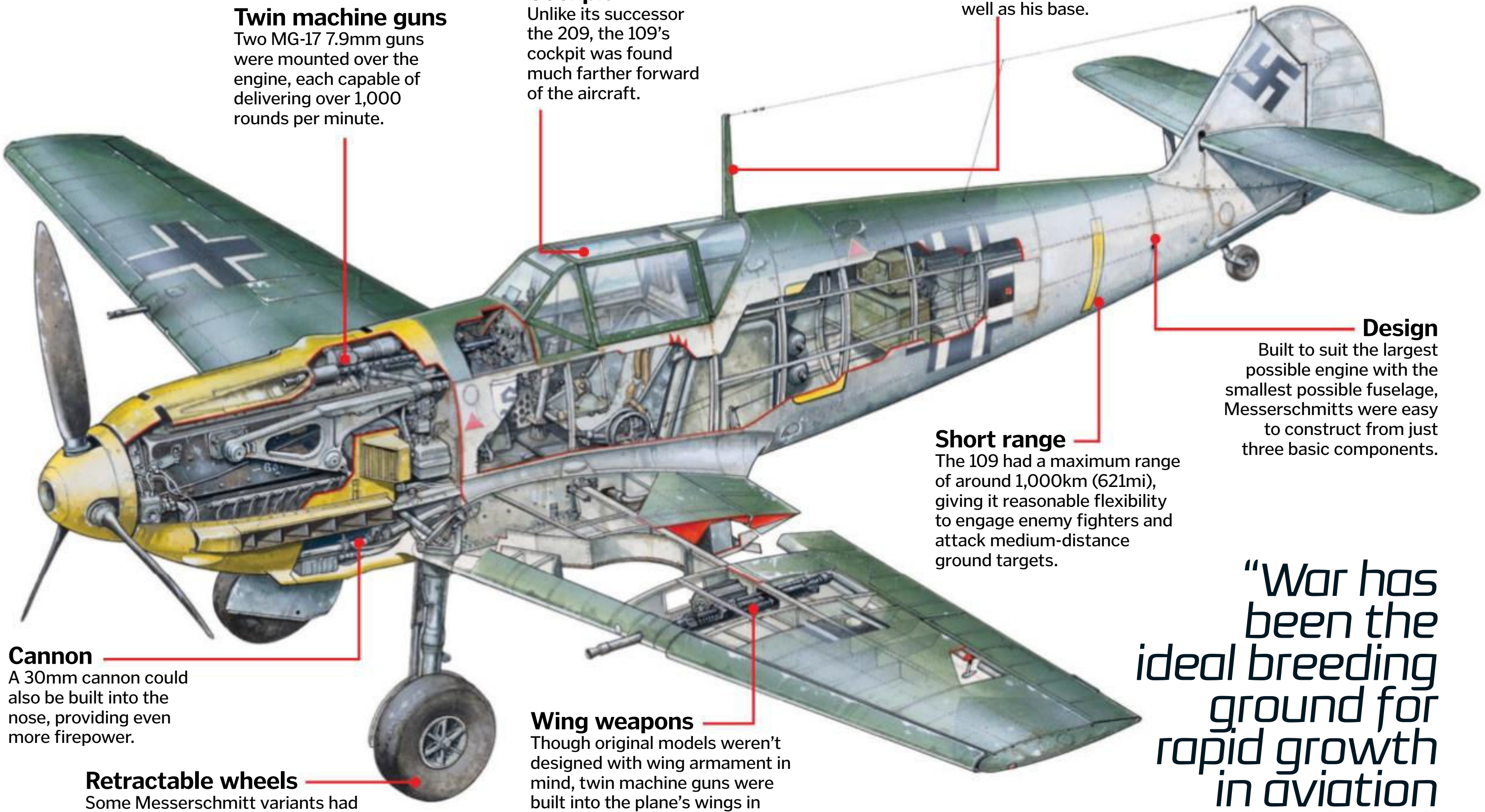
Intelligent wings
These could be altered automatically by up to 20 degrees, increasing the craft's aerodynamics at supersonic speeds.

Engines
Two Pratt & Whitney TF30-P-412s powered the Tomcat, pumping out 186kN (41,800lbf).

DID YOU KNOW? *The SR-72, successor to the SR-71 Blackbird, is under development in an attempt to reach Mach 6*

Messerschmitt Bf 109

This scourge of the skies dominated the battles over early WWII Europe



Twin machine guns
Two MG-17 7.9mm guns were mounted over the engine, each capable of delivering over 1,000 rounds per minute.

Cockpit
Unlike its successor the 209, the 109's cockpit was found much farther forward of the aircraft.

Antenna
A high-frequency antenna, connected to a FuG 16Z radio, kept the pilot in communication with his fellow pilots, as well as his base.

Design
Built to suit the largest possible engine with the smallest possible fuselage, Messerschmitts were easy to construct from just three basic components.

Short range
The 109 had a maximum range of around 1,000km (621mi), giving it reasonable flexibility to engage enemy fighters and attack medium-distance ground targets.

Cannon
A 30mm cannon could also be built into the nose, providing even more firepower.

Retractable wheels
Some Messerschmitt variants had retractable landing gears, which made them more aerodynamic.

Wing weapons
Though original models weren't designed with wing armament in mind, twin machine guns were built into the plane's wings in response to the heavily armed British Spitfires.

> "War has been the ideal breeding ground for rapid growth in aviation technology"

The future of warplanes

With the increasing use of unmanned drones to target and monitor enemy positions and combatants, it has been suggested that traditional fighter jets could eventually lose any purpose in future warfare. In 2013 the Northrop Grumman X-47B prototype unmanned aircraft was the first of its kind to perform a carrier-launch and recovery, signalling a possible future of unmanned strike-bomber aircraft. Boeing's QF-16s – retired F-16 jets modified to be controlled remotely – are now regularly used for aerial target training. While these pilotless jets are used as real-life targets to test missile systems, they demonstrate just how accurate remote flight is becoming.

Both government and industry leaders have admitted that future military aircraft will have to be more closely integrated with artificial intelligence, even with suggestions that manned jets may work alongside pilotless craft. Studies by the Defense Advanced Research Projects Agency (DARPA) have revealed that drones operate more effectively in packs, prompting further research into how drones could work with one another, rather than rely solely on human controllers in combat scenarios. Even before the fifth generation of fighter jets become widely available, including the F-35 Lightning II and Shenyang J-31, world governments are already looking at cost-effective, as well as cutting-edge solutions for the sixth generation of military aeronautics.

The F-35 Lightning II is currently the fifth-generation of fighter aircraft for several global Air Forces and Navies

© Solyo; Thinkstock

On board the Warthog

Why is the A-10 Thunderbolt fighter jet still in use today and just as popular as it was four decades ago when it first took off?

The A-10 Thunderbolt is a single-seat, close-air support fighter jet that also goes by the names Warthog and Tankbuster. Development for the aircraft began in 1967 and its first flight was in 1972. There are several reasons why the A-10 has proved popular enough to weather 40-plus years of advancing military tech – chief among them its combat versatility and high survival rate.

The A-10 boasts a short takeoff and landing capacity with a range of nearly 1,300 kilometres (800 miles). Commonly used for troop support and ground attacks, it can loiter for long periods at low speeds and altitudes below 300 metres (985 feet) and it's capable of soaking up as much damage as it can dish out. Indeed, the A-10 can take direct hits from armour-piercing and explosive shells, has multiple redundancies for its flight systems and, most incredibly, it can return to base on one engine, one tail stabiliser, one elevator and even having lost half a wing! As a result, it's well known among US Air Force pilots for its 'get home' effectiveness.

Modern A-10s have been upgraded from the original 1972 blueprint, of course. Navigation and targeting systems have been dramatically improved. Pilots can now wear night-vision goggles for low-light ops, plus a host of electronic countermeasures and smart-bomb capacity have been installed.

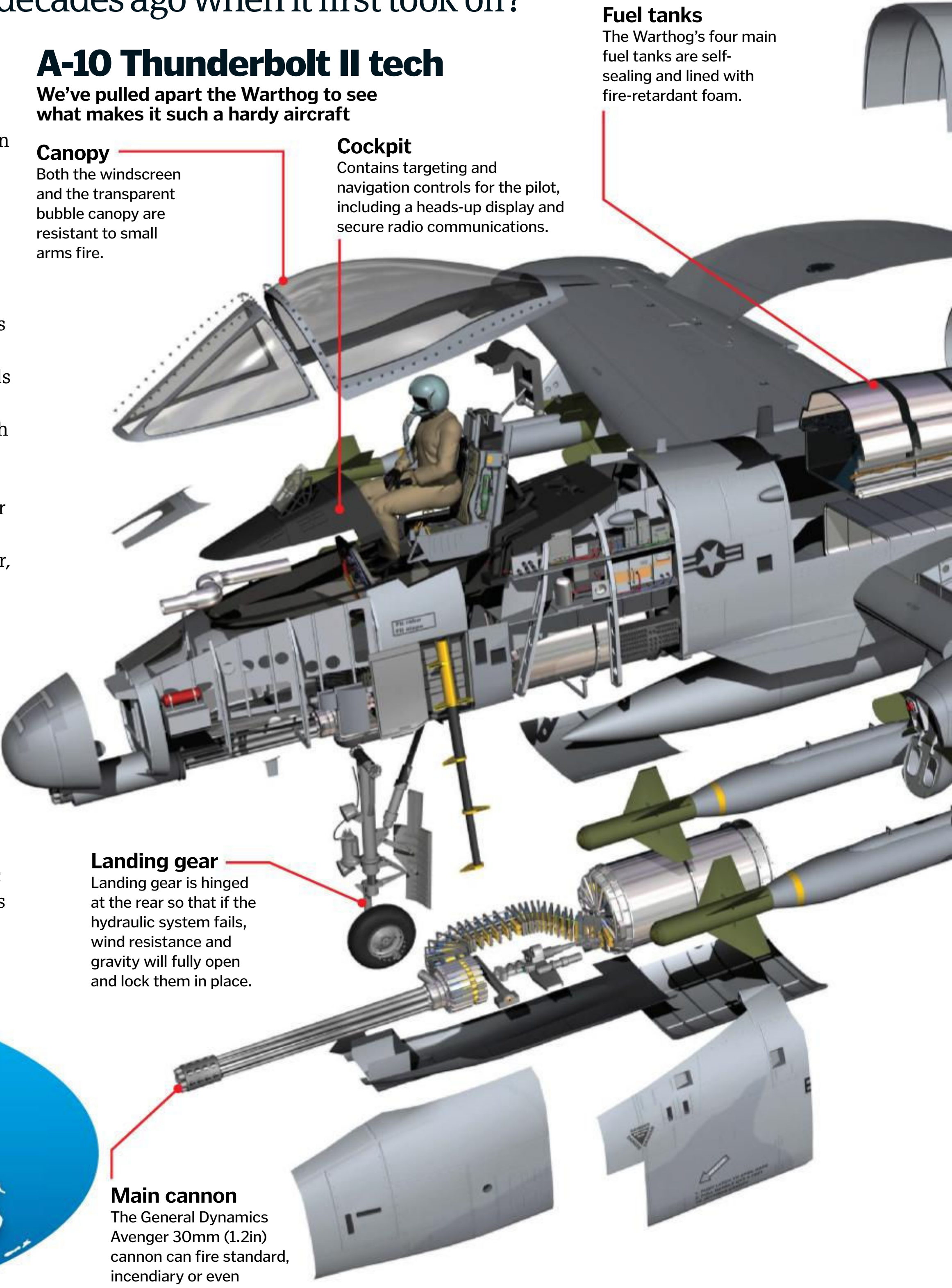
ON THE MAP

A-10s in service

1 Balkans
2 Florida, USA
3 Afghanistan
4 Iraq
5 Libya
6 South Korea

A-10 Thunderbolt II tech

We've pulled apart the Warthog to see what makes it such a hardy aircraft



Canopy
Both the windscreen and the transparent bubble canopy are resistant to small arms fire.

Cockpit
Contains targeting and navigation controls for the pilot, including a heads-up display and secure radio communications.

Fuel tanks
The Warthog's four main fuel tanks are self-sealing and lined with fire-retardant foam.

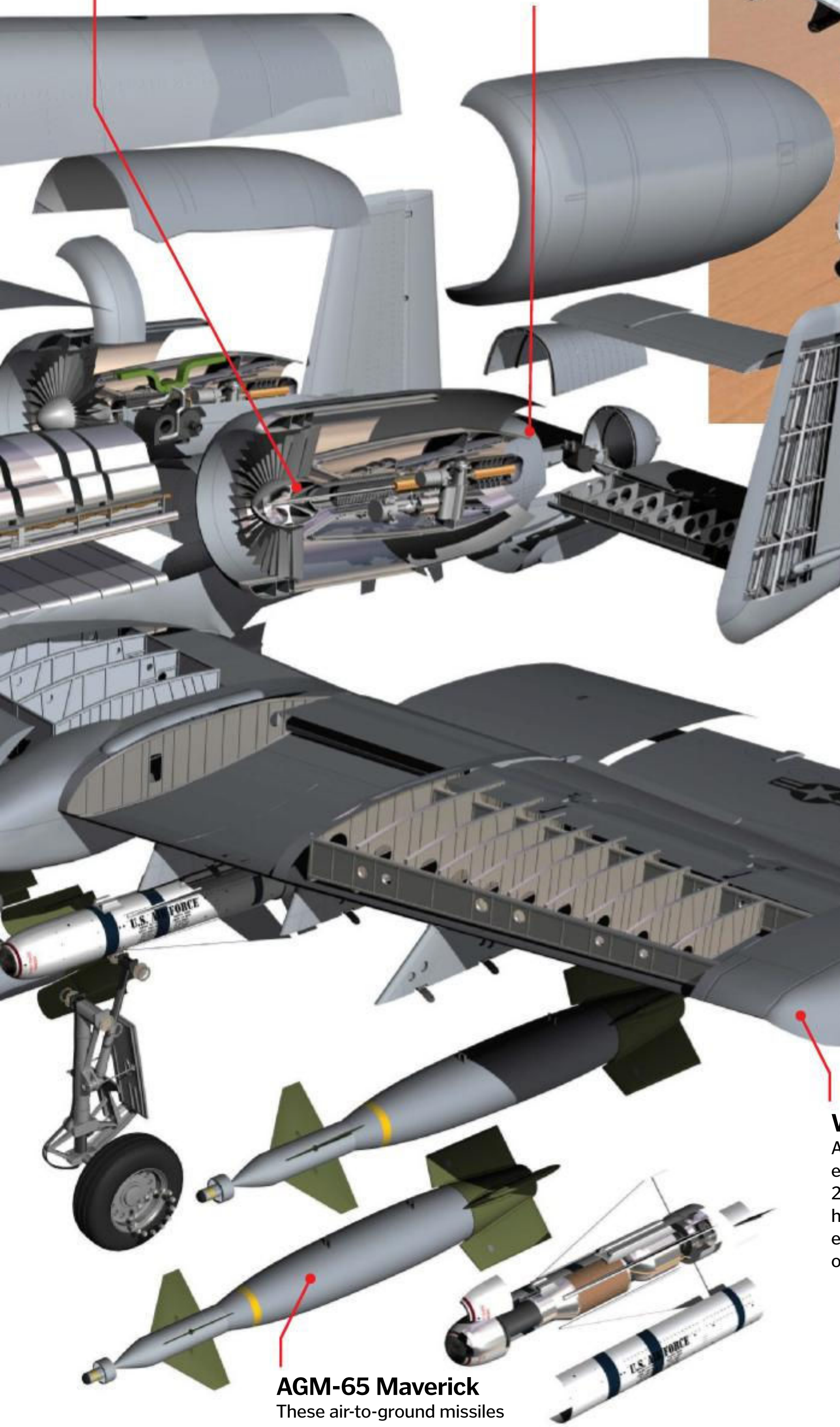
Landing gear
Landing gear is hinged at the rear so that if the hydraulic system fails, wind resistance and gravity will fully open and lock them in place.

Main cannon
The General Dynamics Avenger 30mm (1.2in) cannon can fire standard, incendiary or even depleted-uranium rounds.

THE STATS
TANKBUSTER

LENGTH	16.3m	MAX TAKEOFF WEIGHT	23,000kg	MAX SPEED	706km/h
ORDNANCE CAPACITY	7,260kg	CANNON FIRE RATE	4,200/min	SERVICE CEILING	13,700m

DID YOU KNOW? *The A-10 is so versatile that one has been converted to serve as a weather research platform*



Engines
Two TF34-GE-100, non-afterburning, twin turbofans provide 4,111kg (9,065lb) of thrust each.

Tail
The engines are mounted here to reduce heat signature (for evading heat-seeking missiles) and to enable the plane to fly on just one engine.

Wing
As part of a service life extension programme, 242 new A-10 wing sets have been produced to extend the Warthog's operation until 2040.

AGM-65 Maverick
These air-to-ground missiles have been around as long as the A-10. They're equipped with either contact or delayed-action fuses.

The US Air Force boasts over 360 A-10s in its fleet, operating all around the world, including this one in Afghanistan

Built for defence

The A-10 is robust enough to sustain heavy damage during combat and remain capable of flying away, where other aircraft would be compromised. It's exceptionally well-armoured around the cockpit, where the pilot is vulnerable. Sensitive parts of the flight control system, along with the pilot, are shielded by a 'tub' of titanium armour: 544 kilograms (1,200 pounds) of this super-hard metal is layered in plates up to 3.8 centimetres (1.5 inches) thick around the cockpit, based on the likely trajectories of incoming projectiles. It can withstand fire from similar cannons to its own main weapon, as well as large-calibre rounds. A nylon spall shield also protects the pilot from shrapnel and round fragmentation, while the transparent canopy (which can't afford the same level of protection) can still resist ballistics from small arms.

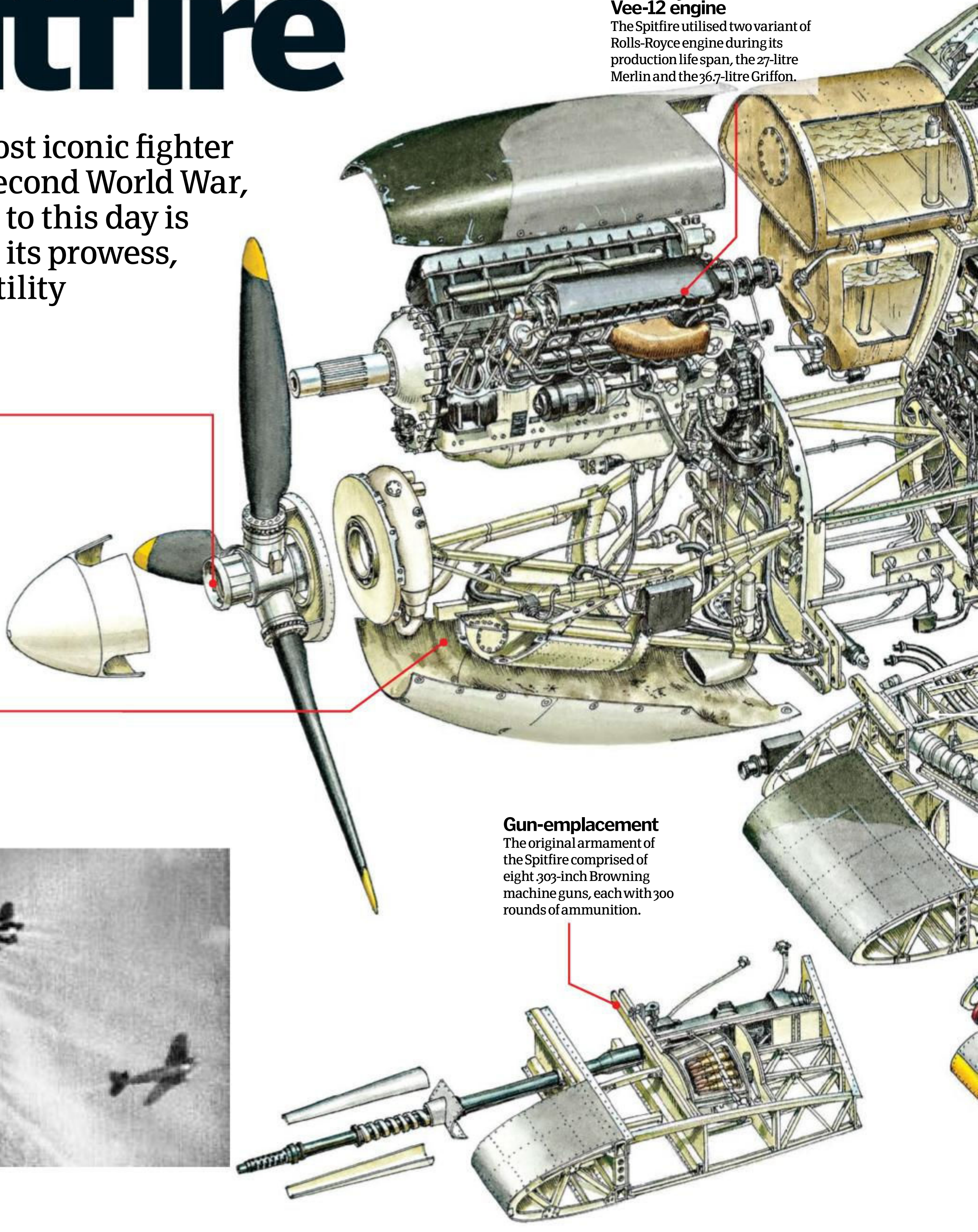
On the offensive

The A-10 can carry nearly half its weight again in armaments and their associated systems, with an external load of up to 7,260 kilograms (16,005 pounds). It's equipped with 11 pylons along which laser weapon guidance and support systems can be attached, plus ordnance. It's capable of carrying a range of cluster and 227-kilogram (500-pound) general-purpose bombs, Hydra rockets, plus up to ten Maverick air-to-ground missiles weighing 304 kilograms (670 pounds) apiece. The latter can destroy a tank in a single hit – however, at a cost of up to £105,000 ($160,000) a pop, a cavalier attitude with the Mavericks is not tolerated. The main weapon is the Avenger 30-millimetre (1.2-inch) cannon mounted under the nose of the A-10, with a top fire rate of 4,200 rounds a minute and an effective range of over 6.5 kilometres (four miles). The cannon can easily disable a main battle tank in the hands of a competent pilot.

© Alex Pang

Supermarine Spitfire

Arguably the most iconic fighter aircraft of the Second World War, the RAF Spitfire to this day is championed for its prowess, grace and versatility



Rolls-Royce Vee-12 engine
The Spitfire utilised two variant of Rolls-Royce engine during its production life span, the 27-litre Merlin and the 36.7-litre Griffon.

Propeller
Original Spitfires had wooden propellers, these were later replaced with variable-pitch propellers, and more blades were added as horsepower increased.

Airframe
The aircraft's airframe was an amalgamation of a streamlined semi-single piece of aluminium alloy with an enclosed cockpit, allowing increased responsiveness and ease of flight.

Gun-emplacement
The original armament of the Spitfire comprised of eight .303-inch Browning machine guns, each with 300 rounds of ammunition.

Video still from gun camera showing the tracers

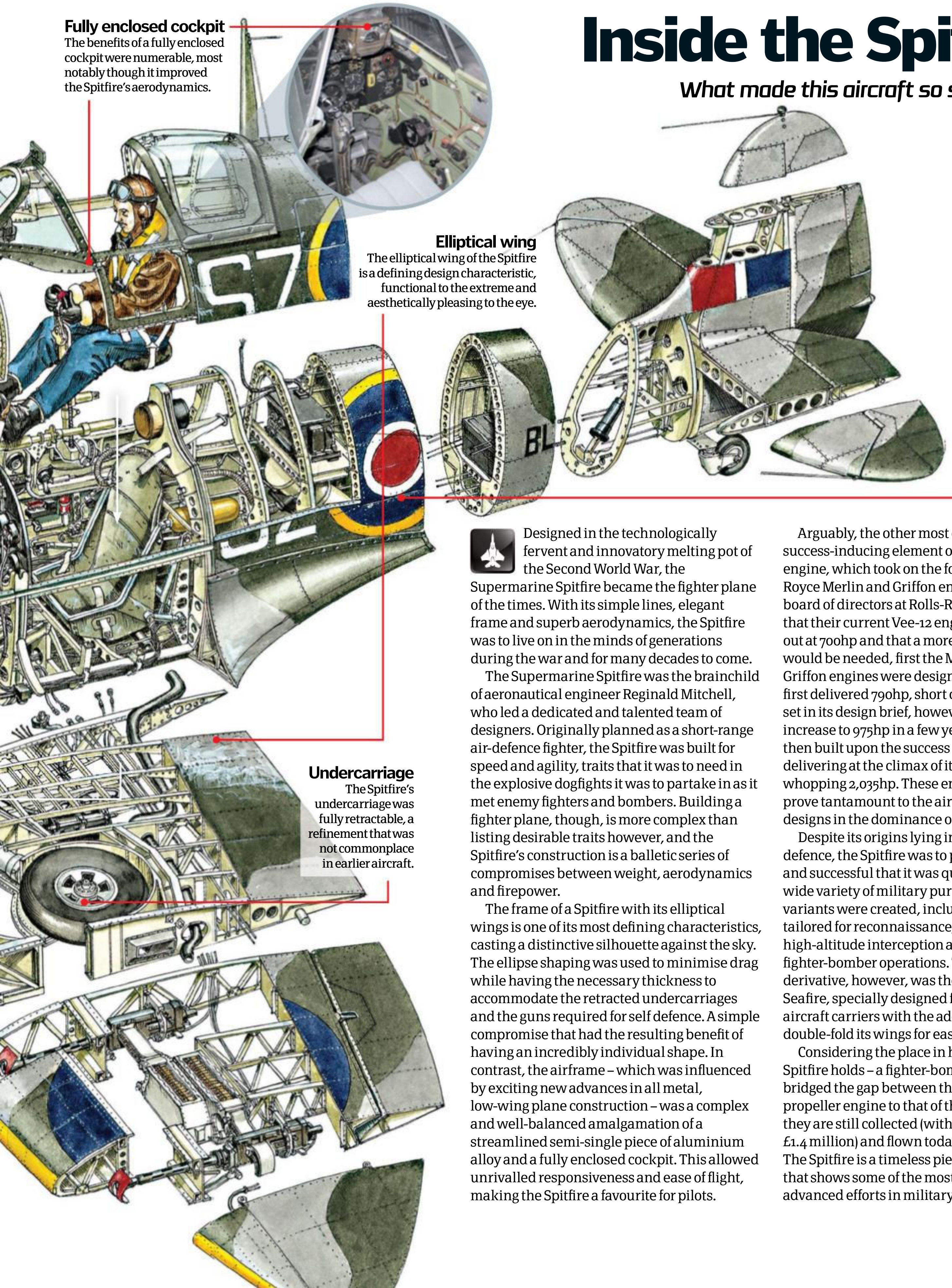
THE STATS
RAF SPITFIRE

MAX SPEED 450mph **RANGE** 400 miles **LENGTH** 32ft 11ins
WINGSPAN 36ft 11in **ARMAMENT** 20mm cannon x4

DID YOU KNOW? *By 1939, approximately ten per cent of all Spitfires had been lost as a result of training accidents*

Inside the Spitfire

What made this aircraft so spectacular?



Fully enclosed cockpit
The benefits of a fully enclosed cockpit were numerable, most notably though it improved the Spitfire's aerodynamics.

Elliptical wing
The elliptical wing of the Spitfire is a defining design characteristic, functional to the extreme and aesthetically pleasing to the eye.

Fuselage
The fuselage of the Spitfire was constructed from toughened aluminium alloy, composing of 19 individual frames.

Undercarriage
The Spitfire's undercarriage was fully retractable, a refinement that was not commonplace in earlier aircraft.

Designed in the technologically fervent and innovatory melting pot of the Second World War, the Supermarine Spitfire became the fighter plane of the times. With its simple lines, elegant frame and superb aerodynamics, the Spitfire was to live on in the minds of generations during the war and for many decades to come.

The Supermarine Spitfire was the brainchild of aeronautical engineer Reginald Mitchell, who led a dedicated and talented team of designers. Originally planned as a short-range air-defence fighter, the Spitfire was built for speed and agility, traits that it was to need in the explosive dogfights it was to partake in as it met enemy fighters and bombers. Building a fighter plane, though, is more complex than listing desirable traits however, and the Spitfire's construction is a balletic series of compromises between weight, aerodynamics and firepower.

The frame of a Spitfire with its elliptical wings is one of its most defining characteristics, casting a distinctive silhouette against the sky. The ellipse shaping was used to minimise drag while having the necessary thickness to accommodate the retracted undercarriages and the guns required for self defence. A simple compromise that had the resulting benefit of having an incredibly individual shape. In contrast, the airframe – which was influenced by exciting new advances in all metal, low-wing plane construction – was a complex and well-balanced amalgamation of a streamlined semi-single piece of aluminium alloy and a fully enclosed cockpit. This allowed unrivalled responsiveness and ease of flight, making the Spitfire a favourite for pilots.

Arguably, the other most defining and success-inducing element of the Spitfire was its engine, which took on the form of the Rolls-Royce Merlin and Griffon engines. Planned by a board of directors at Rolls-Royce who realised that their current Vee-12 engine was topping out at 700hp and that a more powerful variant would be needed, first the Merlin and later the Griffon engines were designed. The Merlin at first delivered 790hp, short of the 1,000hp goal set in its design brief, however this was to increase to 975hp in a few years. The Griffon then built upon the success of the Merlin, delivering at the climax of its advancement a whopping 2,035hp. These engines were to prove tantamount to the airframe and wing designs in the dominance of the Spitfire.

Despite its origins lying in short-range home defence, the Spitfire was to prove so versatile and successful that it was quickly adapted for a wide variety of military purposes. Many variants were created, including designs tailored for reconnaissance, bombing runs, high-altitude interception and general fighter-bomber operations. The most notable derivative, however, was the multi-variant Seafire, specially designed for operation on aircraft carriers with the added ability to double-fold its wings for ease of storage.

Considering the place in history that the Spitfire holds – a fighter-bomber aircraft that bridged the gap between the age of the propeller engine to that of the jet – the fact that they are still collected (with an average cost of £1.4 million) and flown today is unsurprising. The Spitfire is a timeless piece of engineering that shows some of the most creative and advanced efforts in military history.

Image © DK Images

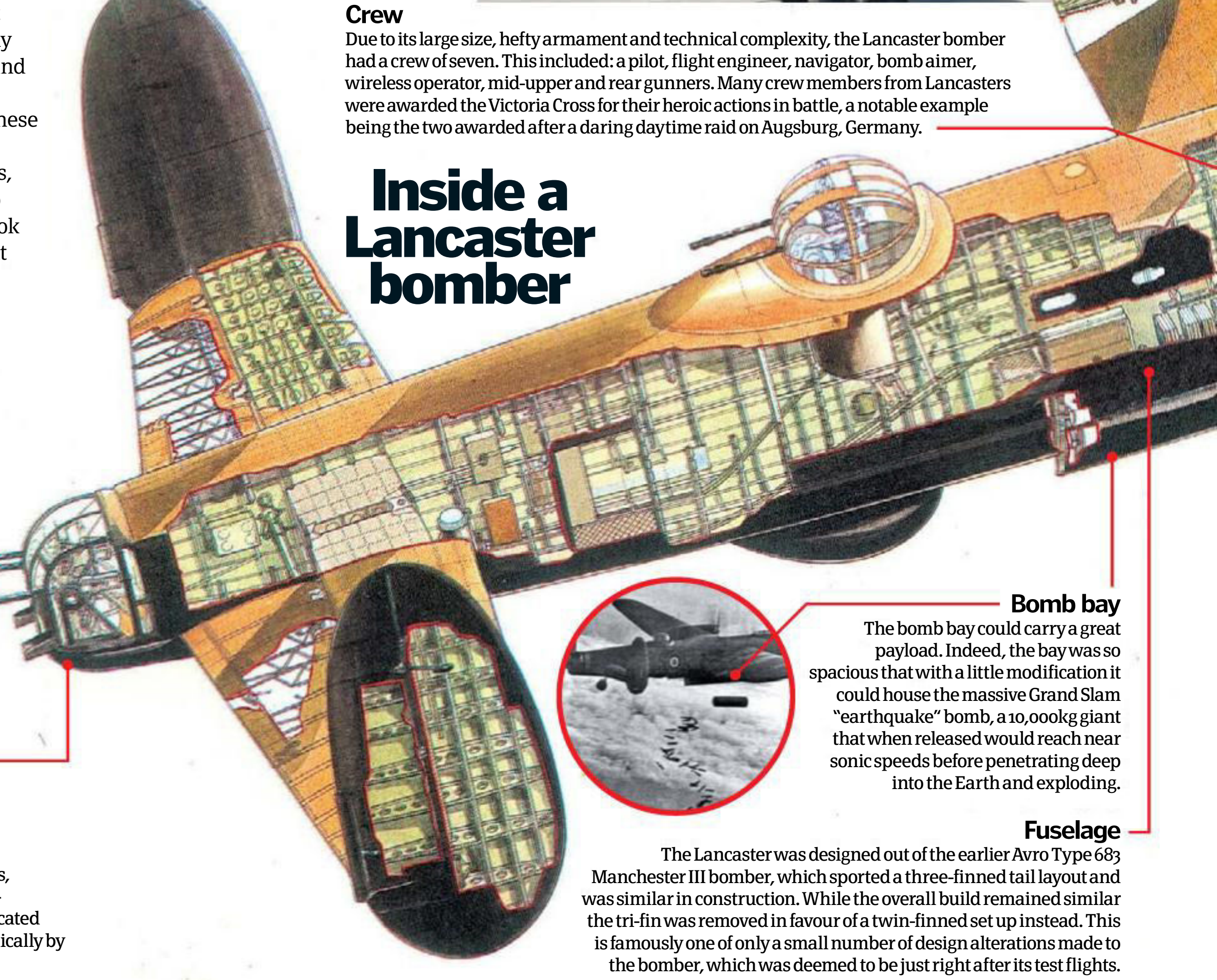
Lancaster bomber

Famed for its prowess and entrenched in popular culture by The Dam Busters film of 1955, the Lancaster bomber played a vital role in securing an allied victory in World War II

Arguably one of the most famous heavy bombers of The Second World War, the Avro-built Lancaster bomber undertook some of the most dangerous and complex missions yet encountered by the RAF. Primarily a night bomber but frequently used during the day too, the Lancasters under Bomber Command flew some 156,000 sorties during the war, dropping 609,000 tons of bombs. Among these bombs was the famous 'bouncing bomb' designed by British inventor Barnes Wallis, a payload that would lead the Lancaster to remain famed long after 1945. We take a look inside a Avro Lancaster to see what made it so successful.

Lancaster bombers dropped 609,000 tons of bombs

Inside a Lancaster bomber



Crew
Due to its large size, hefty armament and technical complexity, the Lancaster bomber had a crew of seven. This included: a pilot, flight engineer, navigator, bomb aimer, wireless operator, mid-upper and rear gunners. Many crew members from Lancasters were awarded the Victoria Cross for their heroic actions in battle, a notable example being the two awarded after a daring daytime raid on Augsburg, Germany.

Turrets
As standard the Lancaster bomber was fitted with three twin 7.7mm turrets in the nose, rear and upper-middle fuselage. In some later variants of the Lancaster the twin 7.7mm machine guns were replaced with 12.7mm models, which delivered more power. The rear and upper-middle turrets were staffed permanently by dedicated gunners, while the nose turret was staffed periodically by the bomb aimer when caught up in a dogfight.

Bomb bay
The bomb bay could carry a great payload. Indeed, the bay was so spacious that with a little modification it could house the massive Grand Slam "earthquake" bomb, a 10,000kg giant that when released would reach near sonic speeds before penetrating deep into the Earth and exploding.

Fuselage
The Lancaster was designed out of the earlier Avro Type 683 Manchester III bomber, which sported a three-finned tail layout and was similar in construction. While the overall build remained similar the tri-fin was removed in favour of a twin-finned set up instead. This is famously one of only a small number of design alterations made to the bomber, which was deemed to be just right after its test flights.

5 TOP FACTS LANCASTER BOMBER

High calibre

1 While 7.7mm machine guns were standard on Lancaster bombers, selective later variants were fitted with twin 12.7mm turrets in both tail and dorsal positions.

Slam-dunk

2 Lancaster bombers often had their already-large bomb bays modified in order to carry the monumental 10,000 kilogram Grand Slam "earthquake" bombs.

Busted

3 A selection of bombers became famous after Operation Chastise, a mission to destroy German dams in the Ruhr Valley, the inspiration for the film *The Dam Busters*.

Collateral

4 Between 1942 and 1945 Lancaster bombers flew 156,000 sorties and dropped approximately 609,000 tons of bombs on military and civilian targets.

Black label

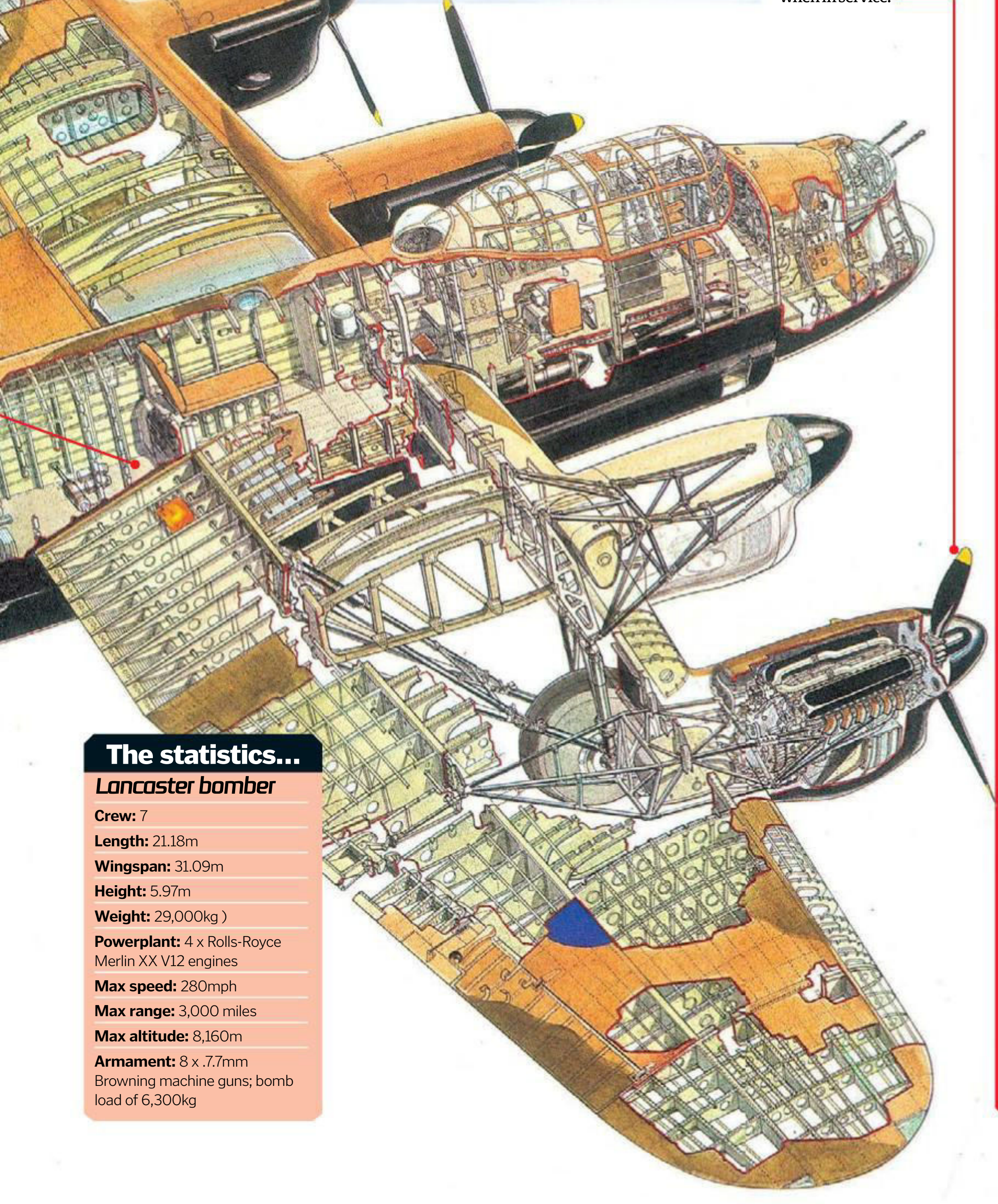
5 The lager company Carling used footage of Lancaster bombers to create a parody of *The Dam Busters* in which a German soldier catches the bouncing bombs.

DID YOU KNOW? *A single Lancaster bomber cost £50,000 in 1942, roughly £1.5 million in today's currency*

Over 7,000 bombers were built

Powerplant

The Lancaster bomber was powered by four Rolls-Royce Merlin V12 engines. These were chosen by the Lancaster's chief designer Roy Chadwick due to their reliability, as the incumbent bomber – the Avro Manchester – had adopted the Rolls-Royce Vulture and had been troubled by engine failure consistently when in service.



The statistics...

Lancaster bomber

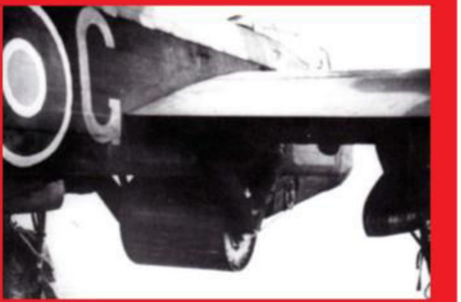
Crew: 7
Length: 21.18m
Wingspan: 31.09m
Height: 5.97m
Weight: 29,000kg)
Powerplant: 4 x Rolls-Royce Merlin XX V12 engines
Max speed: 280mph
Max range: 3,000 miles
Max altitude: 8,160m
Armament: 8 x .7.7mm Browning machine guns; bomb load of 6,300kg

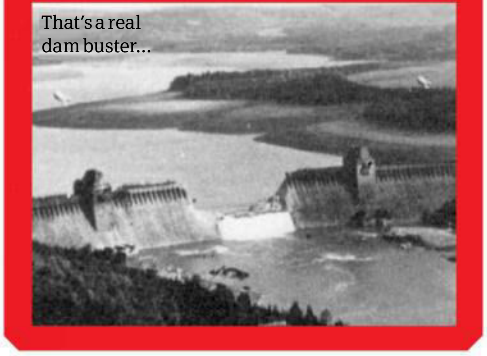
© Bluemoose

The bouncing bomb

One of the most famous parts of the Lancaster's heritage is its role in carrying and releasing the 'bouncing bomb' payload, as glamourised in the 1955 film *The Dam Busters*. The bomb was designed by Barnes Wallis – who was also the creator of the Grand Slam and Tallboy bombs – and was special in its ability to bounce along the top of a surface of water, much akin to skimming a stone. It was designed to counteract and evade German defences below and above the waterline, allowing Allied forces to target German hydroelectric dams and floating vessels.

In May 1943 the bouncing bombs were utilised in Operation Chastise, an allied mission to destroy German dams in the Ruhr Valley. The aircraft used were modified Avro Lancaster Mk IIIs, which had much of their armour and central turret removed in order to accommodate the payload. Despite eight of the Lancasters being lost during the operation, as well as the lives of 53 crew, a small number of bouncing bombs were released and they caused two dams to be breached, one to be heavily damaged and 1,296 civilians to be killed.





That's a real dam buster...

© John Batchelor / www.johnbatchelor.com

> "The Sea Harrier squadron achieved this due to their high manoeuvrability"

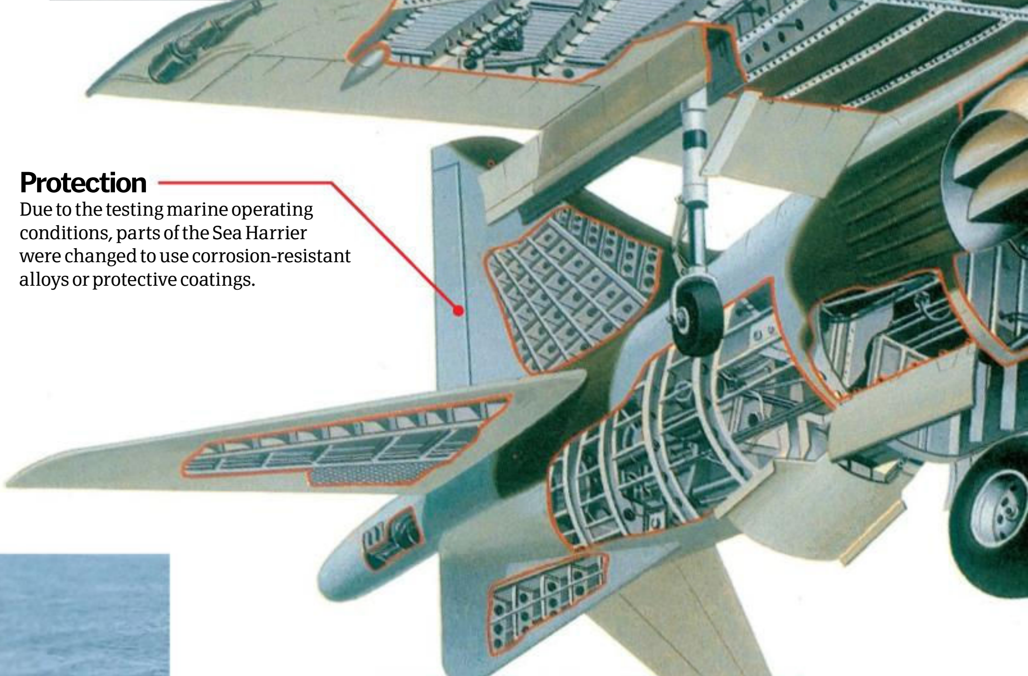
Sea Harrier

Before being retired in 2006, the Sea Harrier dominated the subsonic jet fighter field, changing the dynamics and operation of the strike fighter role forever

The British Aerospace Sea Harrier was the purpose-built naval variant of the Hawker Siddeley Harrier strike fighter, an aircraft famed for its vertical take-off and landing (VTOL) and short take-off and vertical landing (STOVL) capabilities. It worked by adopting the revolutionary single-engine thrust vectoring technology of the regular harrier (see 'Degrees of power' boxout) and partnering it with a modified fuselage – to allow the installation of the superb Blue Fox radar system – bubble-style canopy (larger, allowing greater visibility) and a significantly improved arms load out.

These factors, partnered with the aircraft carrier's ability to launch the aircraft from its ski-jump, allowed the Sea Harrier to perform to a high standard at sea, carrying more weight, detecting enemies sooner and taking them down quickly and efficiently. This was demonstrated most vividly during the Falklands War of 1982, when 28 Sea Harriers operating off British aircraft carriers shot down 20 Argentine aircraft in air-to-air combat without suffering a single loss. The Sea Harrier squadron achieved this due to their high manoeuvrability and tactics while in dogfights – for example, braking/changing direction fast by vectoring their thrust nozzles while in forward flight – as well as their pilots' superior training and early-warning/detection systems.

Thrust vectoring
To achieve VTOL capabilities, the Sea Harrier's engine thrust was directed through four vectoring nozzles, which could rotate through 98.5 degrees from vertically downwards to horizontal.



Protection
Due to the testing marine operating conditions, parts of the Sea Harrier were changed to use corrosion-resistant alloys or protective coatings.

Second-generation Sea Harriers on board an aircraft carrier in the Persian Gulf

Two Indian Navy Sea Harriers fly alongside a US Navy F/A-18F Super Hornet

5 TOP FACTS
HARRIERS

Old boy
1 The Sea Harrier was in service for a total of 28 years, from August 1978 to March 2006. The second-generation Sea Harrier FA2 was introduced in April 1993.

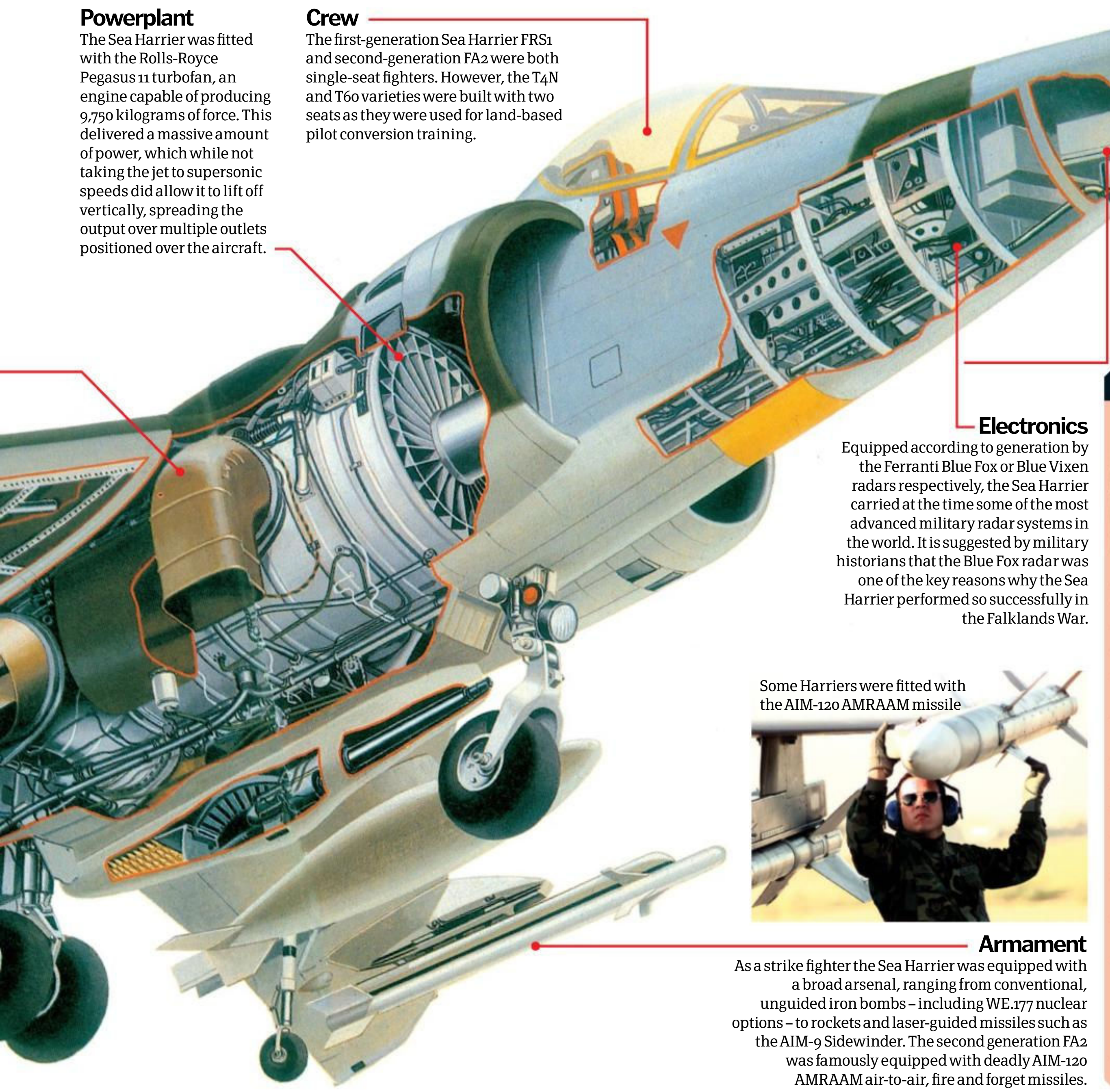
Post-colonial
2 The only other international operator of the Sea Harrier is actually India, who use their own FRS51 variant armed with R550 Magic air-to-air missiles.

Invincible
3 The first ever Sea Harrier confirmed as operational launched off the Invincible class aircraft carrier HMS Invincible in 1981, a purpose-designed VTOL/STOL carrier.

Vixen
4 The second-generation Sea Harrier, the FA2, featured the Blue Vixen radar, the predecessor that formed the basis of the system used in the Eurofighter Typhoon.

Forgetful
5 The second-generation Sea Harrier was also the first British aircraft to be armed with the US AIM-120 AMRAAM, a fire and forget high-explosive air-to-air missile.

DID YOU KNOW? *During the Falkland's conflict the Sea Harrier shot down 20 Argentine aircraft with no air-to-air losses*



Powerplant
The Sea Harrier was fitted with the Rolls-Royce Pegasus 11 turbofan, an engine capable of producing 9,750 kilograms of force. This delivered a massive amount of power, which while not taking the jet to supersonic speeds did allow it to lift off vertically, spreading the output over multiple outlets positioned over the aircraft.

Crew
The first-generation Sea Harrier FRS1 and second-generation FA2 were both single-seat fighters. However, the T4N and T60 varieties were built with two seats as they were used for land-based pilot conversion training.

Electronics
Equipped according to generation by the Ferranti Blue Fox or Blue Vixen radars respectively, the Sea Harrier carried at the time some of the most advanced military radar systems in the world. It is suggested by military historians that the Blue Fox radar was one of the key reasons why the Sea Harrier performed so successfully in the Falklands War.

Some Harriers were fitted with the AIM-120 AMRAAM missile

Armament
As a strike fighter the Sea Harrier was equipped with a broad arsenal, ranging from conventional, unguided iron bombs – including WE.177 nuclear options – to rockets and laser-guided missiles such as the AIM-9 Sidewinder. The second generation FA2 was famously equipped with deadly AIM-120 AMRAAM air-to-air, fire and forget missiles.

The statistics...

Sea Harrier FA2

Crew: 1

Length: 14.2m

Wingspan: 7.6m

Height: 3.71m

Max take-off weight: 11,900kg

Powerplant: 1 x Rolls-Royce Pegasus turbofan (21,500lbf)

Max speed: 735mph

Combat radius: 1,000km

Max range: 3,600km

Max service ceiling: 16,000m

Guns: 2 x 30mm ADEN cannon pods (100 rounds per cannon)

Rockets: 72 SNEB 68mm rockets

Missiles: AIM-9 Sidewinder, AIM-120 AMRAAM, R550 Magic, ALARM anti-radiation missile, Martel missile, Sea Eagle anti-ship missile

Cost: $18 million

Degrees of power
Giving the Sea Harrier lift off

The real showpiece and reason for the lengthy success of the Sea Harrier was its utilisation of the Harrier's revolutionary Pegasus engine partnered with thrust vectoring nozzles. These nozzles could be rotated by the pilot through a 98.5 degree arc, from the conventional aft (horizontal) positioning as standard on aircraft, to straight down, allowing it to take off and land vertically as well as hover, to forward, allowing the Harrier to drift backwards. All nozzles were moved by a series of shafts and chain drives, which insured that they operated in unison (crucial for maintaining stability) and the angle and thrust was determined in-cockpit by the pilot.

This flexibility of control and placement meant that the Sea Harrier was highly manoeuvrable while in the air and could be landed and launched from almost anywhere.

The Sea Harrier's vectoring nozzle in aft position

© Wyrd Light Photography

© John Batchelor / www.johnbatchelor.com

> *"Over 1,000 were lost in the war, either through accidents or enemy attacks"*

Inside a Huey

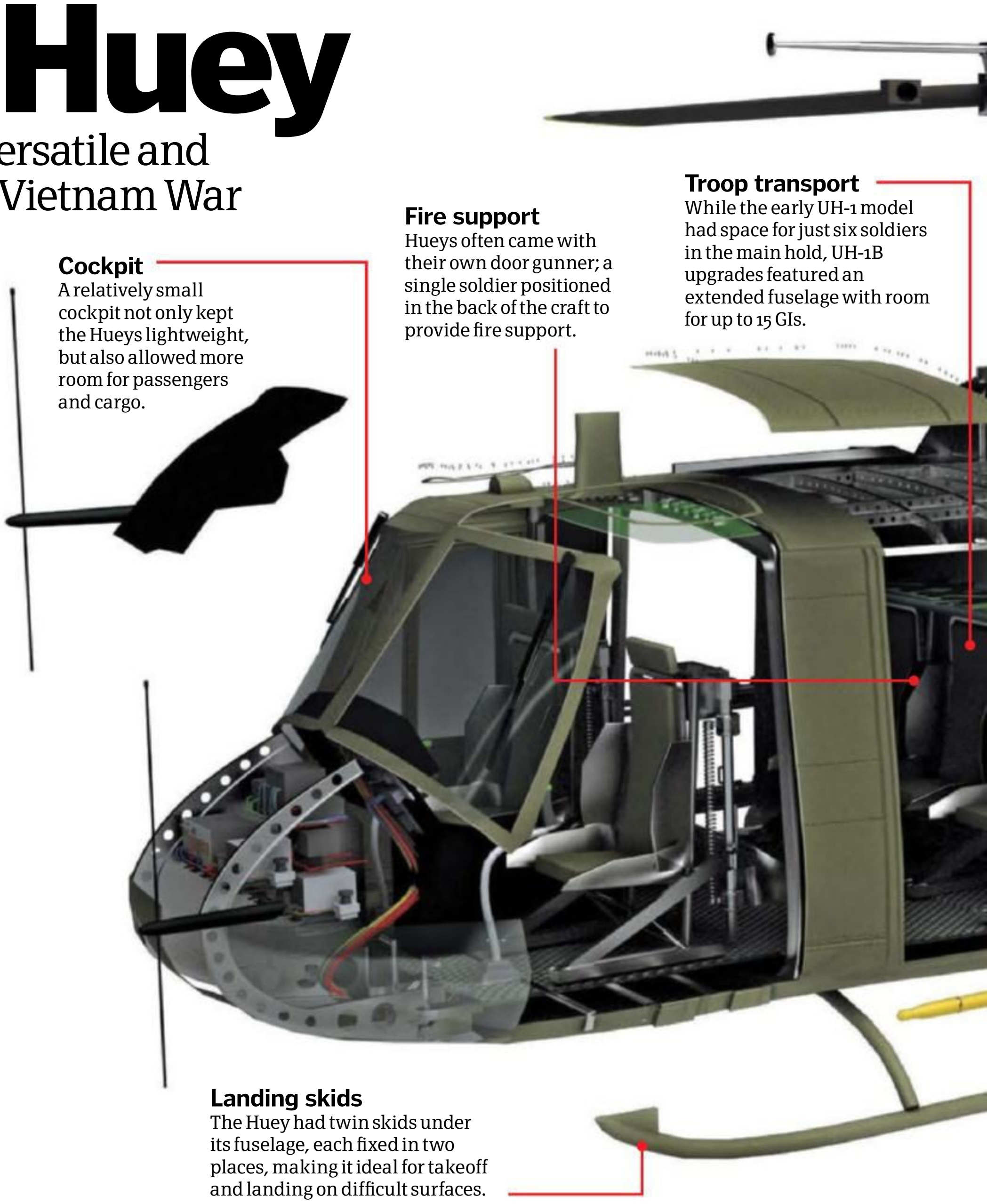
Take a look at one of the most versatile and recognisable vehicles from the Vietnam War

Among the most iconic vehicles of American operations in Vietnam was the multi-functional Bell UH-1 Iroquois helicopter, better known as a Huey. With a flexible design, the Huey helicopter was constantly adapted as a rapid troop transport, medevac, supply transport, as well as a gunship. In Vietnam, the American forces were able to strike deep into enemy territory using Hueys, which had an effective range of up to 510 kilometres (317 miles). Parachute drops were hardly ever used during the entire war, mainly due to the hazards of dropping men over thick jungle. Helicopters, on the other hand, were able to deploy units more precisely in designated clearings.

At the Battle of Ia Drang (1965), Hueys were used to drop US troops within Viet Cong territory, but due to the sheer number of soldiers required for the operation, the transports had to make multiple trips between the landing zone and their base. Once the fight began, many of the vehicles then turned to re-supply and evacuation missions as casualties mounted and ammunition ran low. The versatility of the Huey's simple fuselage, its wide doors and large flat base, proved ideal for housing either injured troops or crates of supplies.

However, many Hueys had little to no armament, making them ideal targets for Viet Cong fighters. Over 1,000 were lost during the war, either through accident or enemy attacks, though many of the craft also came armed. Door gunners equipped with either carbines or mounted medium machine guns were often positioned in the hold, poised to defend the Huey or provide fire support for troops below. Later versions of the Huey also came loaded with 30-calibre machine guns and even rocket pods, with which they could assault enemies on the ground.

During its lifetime, more than 16,000 Bell UH-1 models were produced, with 7,000 seeing active service between 1955-1976. Many are still used today by military and civilian organisations worldwide.



Cockpit
A relatively small cockpit not only kept the Hueys lightweight, but also allowed more room for passengers and cargo.

Fire support
Hueys often came with their own door gunner; a single soldier positioned in the back of the craft to provide fire support.

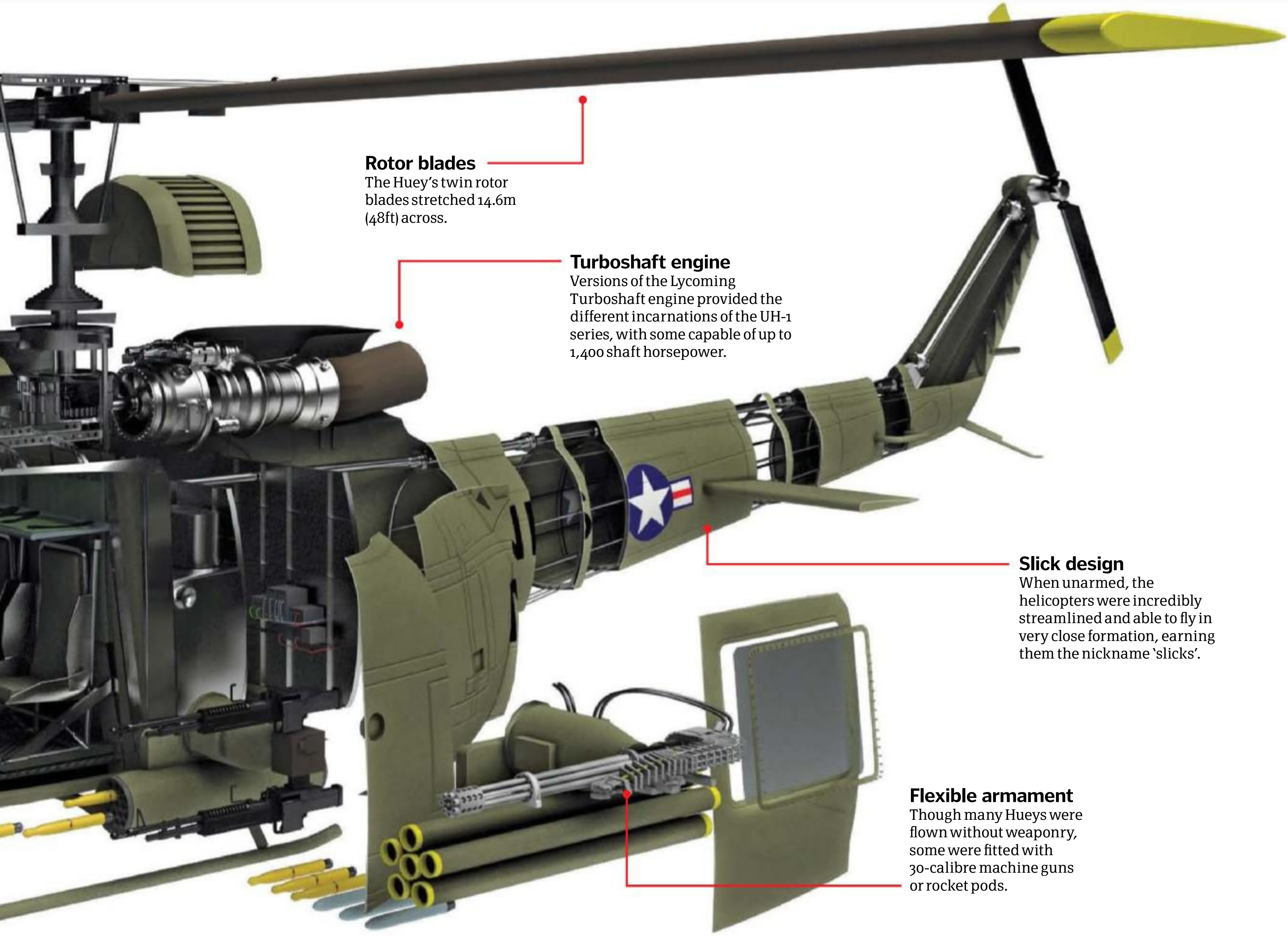
Troop transport
While the early UH-1 model had space for just six soldiers in the main hold, UH-1B upgrades featured an extended fuselage with room for up to 15 GIs.

Landing skids
The Huey had twin skids under its fuselage, each fixed in two places, making it ideal for takeoff and landing on difficult surfaces.

Huey helicopters prepare to transport troops during Operation Wahiawa, South Vietnam

Here a UH-1D is pictured during the Battle of Ia Drang in 1965

DID YOU KNOW? *The medevac version UH-1V, could carry six stretchers and one member of medical staff*



Rotor blades
The Huey's twin rotor blades stretched 14.6m (48ft) across.

Turboshaft engine
Versions of the Lycoming Turboshaft engine provided the different incarnations of the UH-1 series, with some capable of up to 1,400 shaft horsepower.

Slick design
When unarmed, the helicopters were incredibly streamlined and able to fly in very close formation, earning them the nickname 'slicks'.

Flexible armament
Though many Hueys were flown without weaponry, some were fitted with 30-calibre machine guns or rocket pods.

The modern 'Super Huey'

Bell's UH-Y1, also called the Yankee and the 'Super Huey', is one of the latest stages in the evolution of the Huey. With all the flexibility, reliability and efficiency of the original UH, this 21st-century beast of the air packs in the most up-to-date military-grade tech. As well as a night-vision-compatible cockpit and an electronic warfare self-protection suite, this modern Huey also notably has two twin rotor blades, unlike the original UH series.

Also different to the original Hueys, the UH-1Y craft have vastly improved safety and protective features, including a crashworthy fuel system and energy-absorbing landing gear. Capable of carrying heavier payloads and flying further than its predecessor, the UH-1Y was deployed in Afghanistan in 2009 where it was utilised by the US Marine Corps.

US Marine Corps pilots landing a UH-1Y during training exercises in Pendleton, California

© Alamy

> "It was famed for its ability to pass the sound barrier, going supersonic in a shallow dive"

Sea Vixen

Sporting one of the most notable post-war aircraft designs, the de Havilland Sea Vixen was a fearsome all-weather jet fighter, capable of taking its pilots supersonic and delivering a titanic amount of next-generation firepower

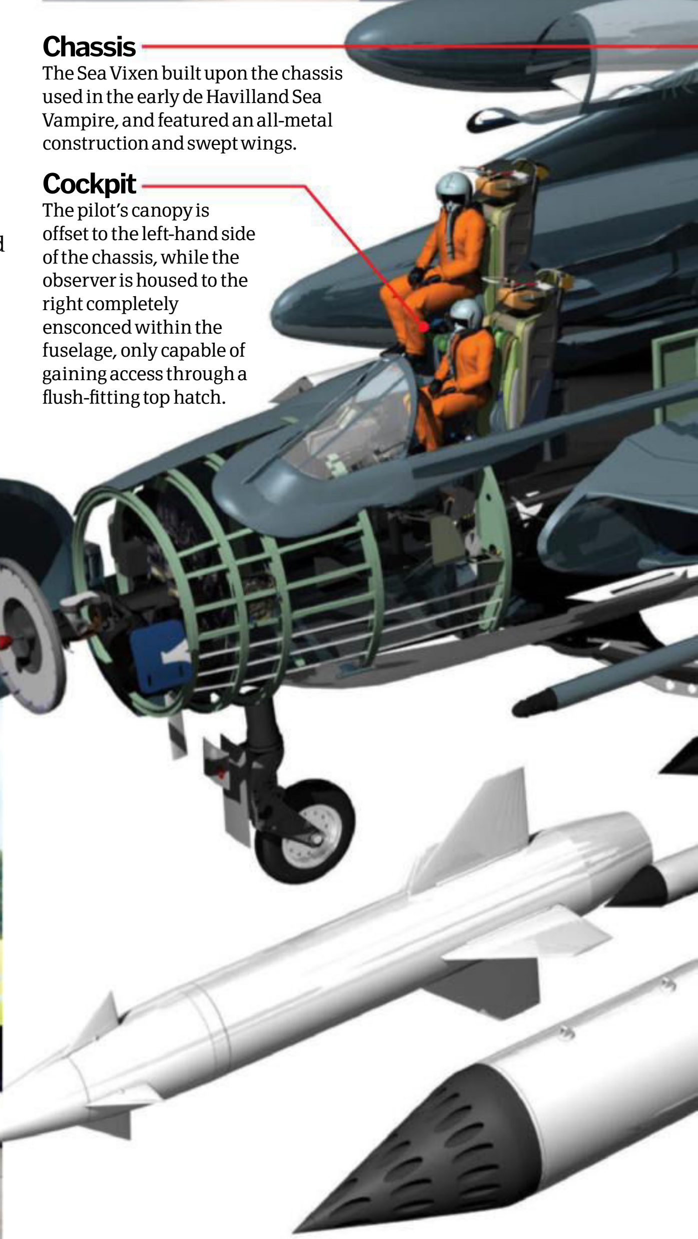
The first British fighter to be fitted purely with missiles, rockets and bombs – rather than the heavy calibre machine guns relied upon in WWI and WWII – the Sea Vixen was a first generation jet fighter employed by the Fleet Air Arm of the Royal Navy. It was famed for its ability to pass the sound barrier, going supersonic when in a shallow dive (hitting a top speed of 690mph) and saw action in multiple missions in the Middle East and Africa during the Sixties and Seventies.

Designed to be deployed from aircraft carriers as an all-weather fighter and high-speed reconnaissance jet, the Sea Vixen worked by partnering the reinforced twin-boom tail layout as seen on its predecessors the Sea Vampire and Sea Venom, with the colossal power generated by twin Rolls-Royce Avon 208 turbojet engines, each capable of delivering 7,500lb of thrust. This gave the Vixen massive speed, a range of 600 miles – the twin-boom layout allowed for more fuel tanks – and a flexibility to engage targets at sea, on land and in the air, as well as conduct lengthy patrols.

The armament of the Sea Vixen was revolutionary for the time. With six hardpoints (areas that weapons can be mounted on) capable of being fitted with a selection of Firestreak air-to-air missiles, which sported annular blast fragmentation warheads, SNEB rocket pods with 68 unguided explosive-tipped rockets each, and whopping 500-pound air-to-ground bombs. Detection of targets was also state-of-the-art, the Sea Vixen was fitted with the GEC AI.18 Air Interception radar, which gave the jet great strategic vision even at night or in particularly poor visibility conditions.

In 2015, only one working Sea Vixen now survives in the entire world, which is maintained by Naval Aviation Ltd and operated from Yeovilton, Great Britain. After being declassified as a military aircraft and entered onto the civil register (changing its tag from XP924 to G-CVIX), the aircraft was used for a time as an advertising vehicle for Red Bull but has recently been repainted with its original Fleet Air Arm 899 NAS colours and now flies regularly as part of demonstrations and air shows across the United Kingdom.

© Nigel Ish


Chassis
The Sea Vixen built upon the chassis used in the early de Havilland Sea Vampire, and featured an all-metal construction and swept wings.

Cockpit
The pilot's canopy is offset to the left-hand side of the chassis, while the observer is housed to the right completely ensconced within the fuselage, only capable of gaining access through a flush-fitting top hatch.

The Red Bull plane repainted in its original livery

5 TOP FACTS
SEA VIXEN

Disaster

1 On 6 September 1952, a prototype Sea Vixen disintegrated in mid-air at the Farnborough Airshow while attempting to break the sound barrier, killing 31 people.

Breaker

2 One of the crew killed at the Farnborough Airshow was John Derry, the first British person to exceed the speed of sound in a de Havilland DH 108 in September 1948.

Home

3 The only remaining Sea Vixen capable of flight was kept at Bournemouth International Airport in Dorset, Britain. Until an accident occurred on the runway in 2014

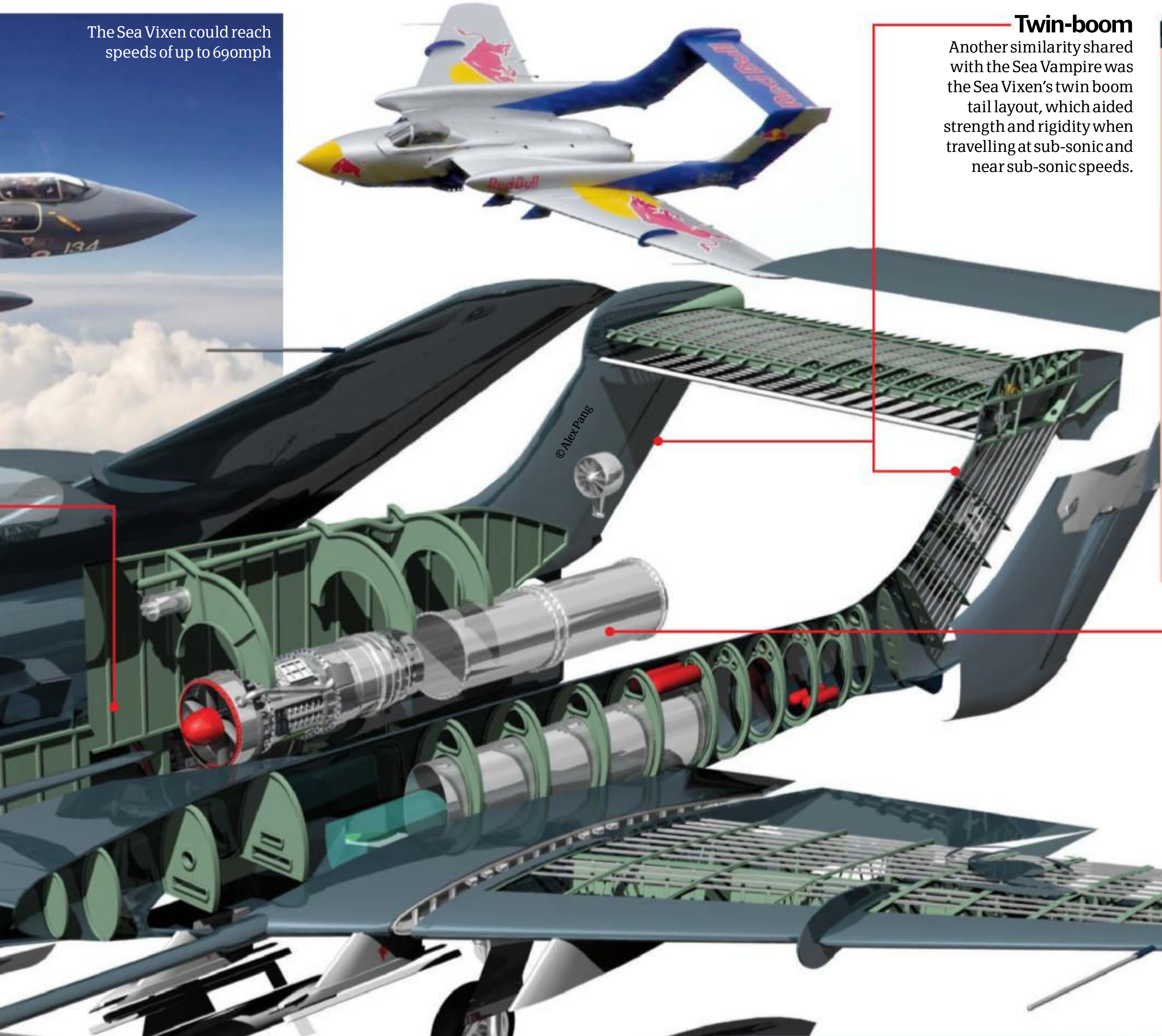
Merger

4 The Sea Vixen was produced by the de Havilland company, but post merger with the Hawker Siddeley aerospace group, it was renamed the Hawker Siddeley Sea Vixen.

Vintage

5 De Havilland Aviation is a company that specialises in acquiring and reconditioning most military aircraft. You can find out more at www.dehavillandaviation.com

DID YOU KNOW? *There is only one fully functioning Sea Vixen left in the world*



The Sea Vixen could reach speeds of up to 690mph

© Alex Pang

Twin-boom

Another similarity shared with the Sea Vampire was the Sea Vixen's twin boom tail layout, which aided strength and rigidity when travelling at sub-sonic and near sub-sonic speeds.

Powerplant

It was powered by two Rolls-Royce Avon 208 turbojet engines, each capable of producing 7,500 pounds of thrust. This massive power allowed the jet to go supersonic in a shallow dive.

Armament

The Vixen had six hardpoints upon which it could carry a combination of Matra rocket pods with 18 SNEB 68mm rockets each, Firestreak air-to-air missiles and 227kg high-explosive bombs.

The statistics...

© Tony Hisgett

Sea Vixen

Crew: 2

Length: 16.9m

Wingspan: 15.5m

Empty weight: 12,680kg

Loaded weight: 18,860kg

Powerplant: 2 x Rolls-Royce Avon Mk.208 turbojets

Max speed: 690mph

Range: 790mi

Service ceiling: 14,630m

Armament: 4 x Matra rocket pods with 18 SNEB 68mm rockets each, 4 x Red Top air-to-air missiles, 2 x 227kg bombs

A Sea Vixen with Red Bull advertising

"Since the first flight the Lynx has been continually upgraded and developed"

Westland Lynx

A record breaker and for 40 years – can anything beat the Lynx?

The Westland Lynx forms the backbone of the British Army and Navy helicopter forces. Entering military service in 1978, it had already set world speed records during testing. Introduced as a utility helicopter in 1971, the Lynx is a twin gas turbine-powered, two-pilot aircraft, with advanced control systems, a four-blade, semi-rigid rotor and, thanks to the fundamental stability and unrivalled agility of the basic airframe, it has performed in almost every role imaginable.

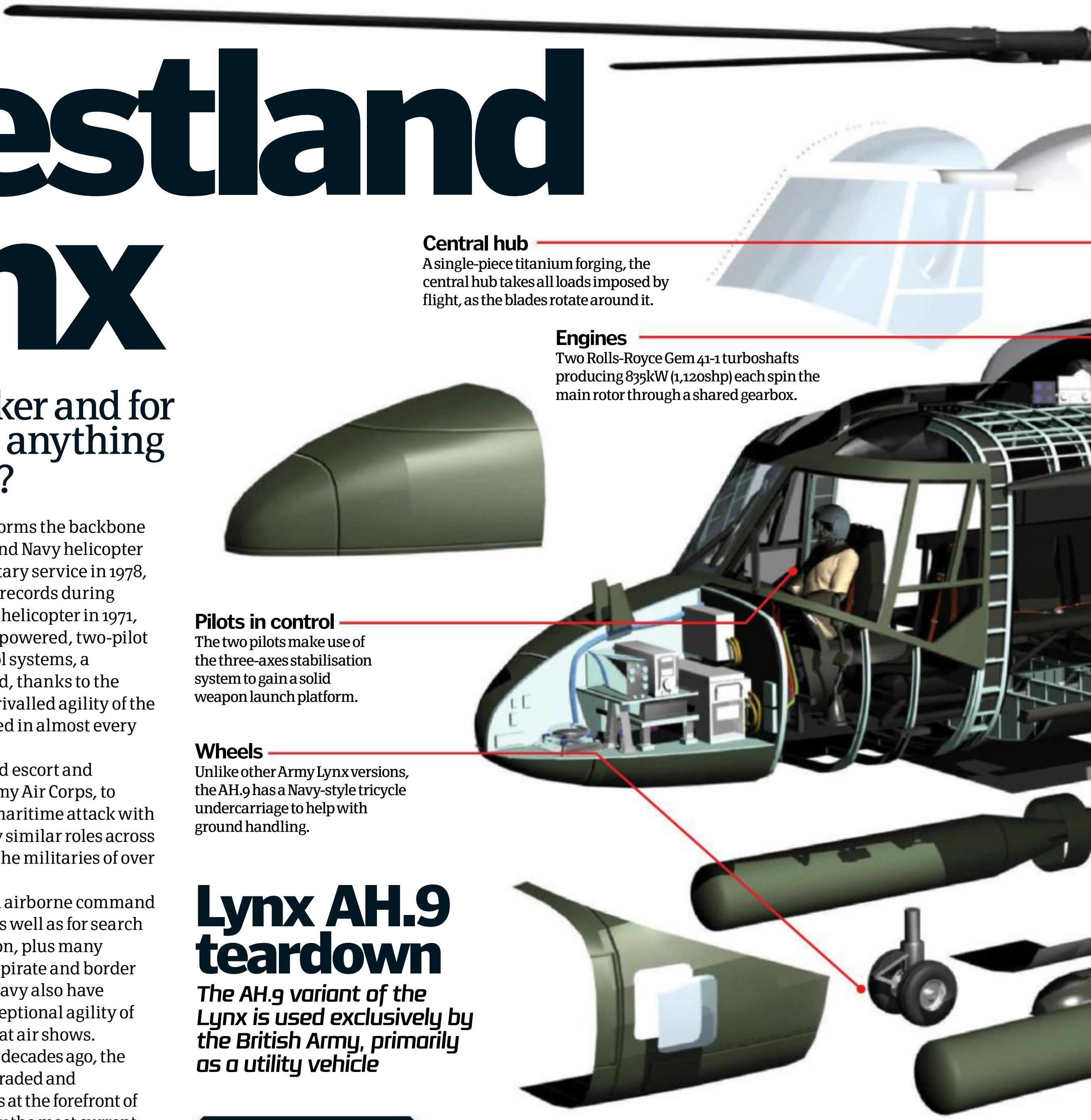
From troop transport, armed escort and anti-tank warfare with the Army Air Corps, to anti-submarine warfare and maritime attack with the Fleet Air Arm, and in many similar roles across the globe, the Lynx is used by the militaries of over a dozen countries worldwide.

This helicopter is used as an airborne command post, a fire support platform, as well as for search and rescue, casualty evacuation, plus many specialist roles including anti-pirate and border patrol. The British Army and Navy also have display teams that use the exceptional agility of the Lynx to amaze the crowds at air shows.

Since its first flight, over four decades ago, the Lynx has been continually upgraded and developed, ensuring it's always at the forefront of technology, as demonstrated by the most current variant, the Super Lynx. Army models kept the traditional landing 'skids' until only recently, when they adopted the tricycle-wheeled undercarriage used by the Navy to aid ground handling.

Improvements in navigation, communication and radar systems in Navy derivatives have ensured that British helicopter capability at sea is world leading, while Army versions have similarly demonstrated their ability to evolve with the changing requirements of modern warfare.

The latest variants are excelling on the battlefield, using state-of-the-art weapons and tactics including night-vision-assisted operations. The next generation of Lynx (the Wildcat) is currently undergoing flight testing on land and sea, ensuring many years of continued service.



Central hub
A single-piece titanium forging, the central hub takes all loads imposed by flight, as the blades rotate around it.

Engines
Two Rolls-Royce Gem 41-1 turboshafts producing 835kW (1,120shp) each spin the main rotor through a shared gearbox.

Pilots in control
The two pilots make use of the three-axes stabilisation system to gain a solid weapon launch platform.

Wheels
Unlike other Army Lynx versions, the AH.9 has a Navy-style tricycle undercarriage to help with ground handling.

Lynx AH.9 teardown

The AH.9 variant of the Lynx is used exclusively by the British Army, primarily as a utility vehicle

The statistics...

Westland Lynx AH.9

Length: 15.2m (50ft)

Rotor diameter: 12.8m (42ft)

Height: 3.8m (12.4ft)

Disc area: 128.7m^2 (1,385ft^2)

Empty weight: 3,291kg (7,255lb)

Max takeoff weight: 5,330kg (11,750lb)

Powerplant: 2 x Rolls-Royce Gem 41-1 turboshaft, 835kW (1,120shp) each

Max speed: 324km/h (201mph)

Range: 528km (328mi)

© AgustaWestland

5 TOP FACTS WESTLAND LYNX

Unbeatable record?

1 The world helicopter speed record set by G-LYNX still stands over 25 years later. With the latest fast rotorcraft moving away from eligible designs, G-LYNX's record may never be broken.

War veteran

2 The Lynx has proven capabilities in many combat environments, including disabling the Argentine submarine Santa Fe during the Falklands campaign, and sinking several Iraqi ships in the Gulf Wars.

Blow me down

3 Naval versions of the Lynx have the ability to angle the main rotor blades downwards to generate negative lift, pushing the aircraft onto the deck of a ship after landing.

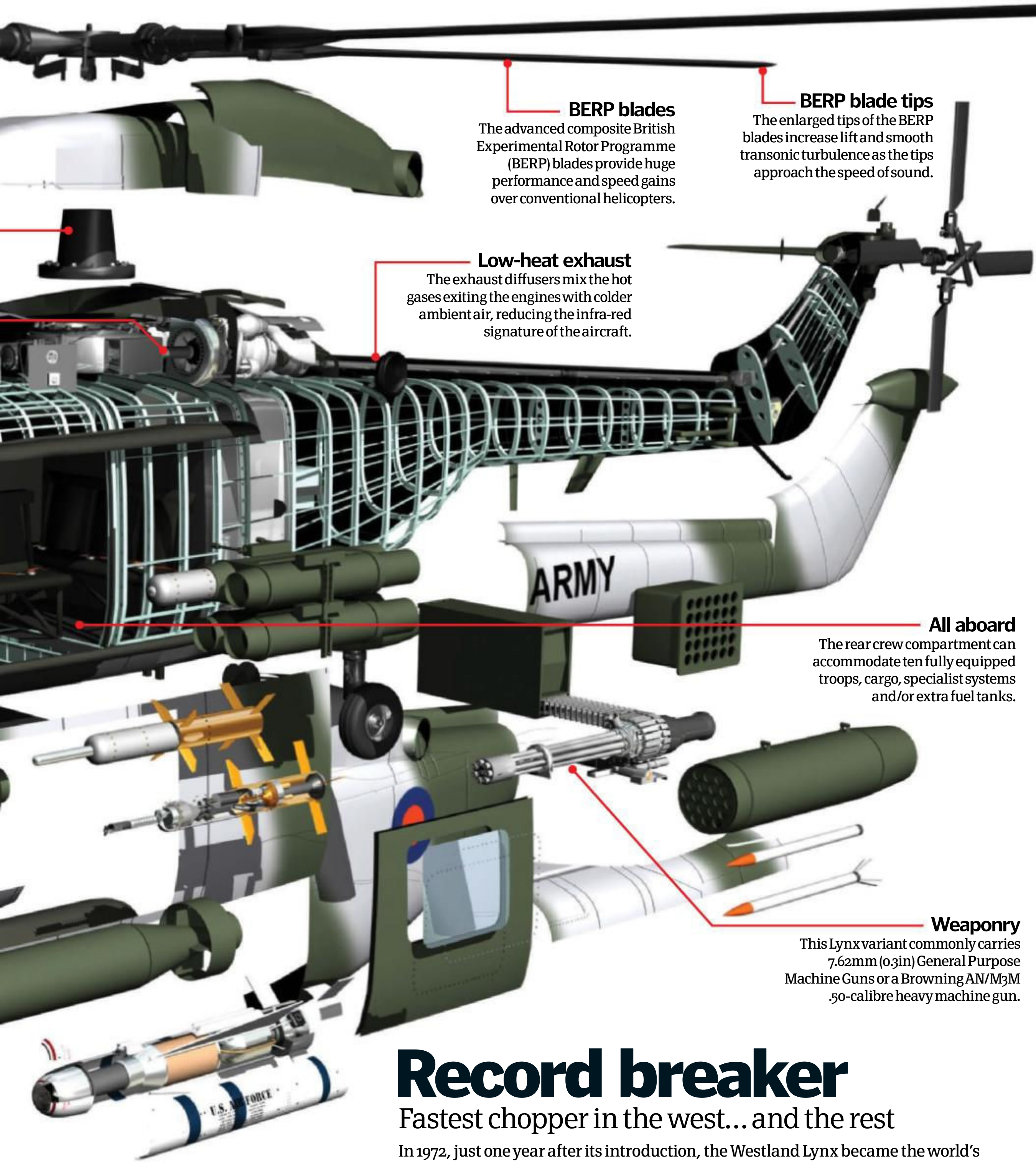
More speed?

4 An even faster variant of the Lynx was proposed but never built. It would not have qualified for a world speed record, though, as it had aeroplane-like wings beneath the rotor.

Super-strong

5 The key component in the Lynx rotor is a solid titanium hub around which everything spins. This provides the strength needed for both high-speed and high-agility manoeuvres.

DID YOU KNOW? *The Lynx is one of the few helicopters in the world that can perform advanced aerobatics, including loops*



BERP blades

The advanced composite British Experimental Rotor Programme (BERP) blades provide huge performance and speed gains over conventional helicopters.

BERP blade tips

The enlarged tips of the BERP blades increase lift and smooth transonic turbulence as the tips approach the speed of sound.

Low-heat exhaust

The exhaust diffusers mix the hot gases exiting the engines with colder ambient air, reducing the infra-red signature of the aircraft.

All aboard

The rear crew compartment can accommodate ten fully equipped troops, cargo, specialist systems and/or extra fuel tanks.

Weaponry

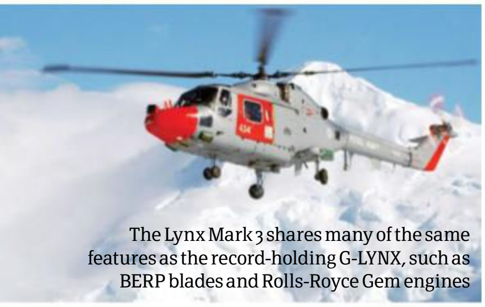
This Lynx variant commonly carries 7.62mm (0.3in) General Purpose Machine Guns or a Browning AN/M3M .50-calibre heavy machine gun.

© Alex Pang

Record breaker

Fastest chopper in the west… and the rest

In 1972, just one year after its introduction, the Westland Lynx became the world's fastest helicopter when airframe XX153 set a new world speed record over 15-kilometre (9.3-mile) and 25-kilometre (15.5-mile) straight courses by flying at an average 321.7 kilometres (199.9 miles) per hour. In 1978 a heavily modified Russian Mil Mi-24 'Hind' increased this to 368.4 kilometres (228.9 miles) per hour. With Westland under political and commercial pressure, it was decided that an attempt would be made to reclaim the record. Westland re-registered Lynx airframe ZB500 as G-LYNX, and began a programme of extensive modification. More powerful Rolls-Royce Gem 60 gas turbines were fitted, along with a water-methanol injection system, but the biggest performance contribution came from the British Experimental Rotor Programme (BERP). On 8 August 1986, these advanced rotor blades carried G-LYNX pilot Trevor Egginton and his flight engineer Derek Clews to the world record speed of 400.9 kilometres (249.1 miles) per hour, which still stands to this day.



The Lynx Mark 3 shares many of the same features as the record-holding G-LYNX, such as BERP blades and Rolls-Royce Gem engines

© Crown Copyright

Top trumps: MILITARY CHOPPERS

© AgustaWestland

WESTLAND LYNX AH.9

The Lynx is the smallest and lightest aircraft of the three in this roundup, which allows it to operate from small ships. The Lynx can carry more troops and is far more agile than its larger counterparts, but has less power so cannot carry as high a payload or as many weapons.

© US Navy

SIKORSKY SH-60 SEAHAWK

The Seahawk has a huge range advantage over its competitors – almost twice that of the Hind. The common parts it shares with the other aircraft in the Blackhawk family make maintenance and repair highly cost effective. However, it cannot operate from small ship decks, and is not particularly agile.

© BrokenSphere

MIL MI-24 HIND

The Hind is heavily armoured, heavily armed, extremely fast and very powerful. It is not used by the Navy due to its limited range, and its size means it is not very agile. Despite the variety of fearsome weapons that it can carry on its hardpoints, the Hind has often lacked a reliable anti-armour capability.

Strategic bombers

Dedicated bombing aircraft act as damage-dealing workhorses, engaging enemy targets 24/7 regardless of weather conditions and the hazardous theatre of war. We take to the skies for a closer look at some of its key players

Deployed to support ground troops in the Libyan civil war, the B-1B Lancer packs a powerful payload

© USAF

© USAF

The battlefield has changed. Now, more than ever before, the theatre of war is in flux, rebuilding itself minute-by-minute, breaking down the conventional barriers of geography, geometry and time. Weapons systems are co-evolving along with defence systems at a ferocious rate, fuelled by the continued, perpetual rage of a segregated planet. The relationship between organic and inorganic matter is becoming fused, co-dependent and augmented, in order to generate the versatility demanded when fighting in the 21st Century. Fluidity and reaction speed is now paramount, for if you have the inability to engage immediately on a global scale, the parameters shift and the chance dissipates.

Strategic bombers are positioned at the leading edge of this technological and logistical war, built to offer the range, payload, durability and speed to engage a hostile target quickly and efficiently, no matter their location or levels of defence. Installed with the most cutting-edge technology and weapons systems available these machines excel in delivering their human operator near-omnipresent power. They include missiles that can transcend the speed of sound three times over, bombs that are guided by invisible, omnipresent satellite links to their targets, and nuclear warheads over ten times the power of that which despoiled Hiroshima. Strategic bombers are also capable of remaining airborne for days, protected by their insane speed and large weapons basket (the range in which they can launch weapons at a target without themselves being engaged).

5 TOP FACTS
Bombers

Fortress

1 The B-1 Lancer was originally conceived in the late-Sixties as a supersonic bomber with the range and payload to replace the famous Boeing B-52 Stratofortress.

Father

2 According to Russian government sources, it was a Tu-160 that dropped the 'Father of all bombs'. The government commented: 'all that's alive merely evaporates'.

Iraq

3 The B-1 Lancer was one of the most used aircraft during the Iraq war. One of its most notable missions was an unsuccessful attempt to kill Saddam Hussein.

Swan

4 Russian pilots train to fly the Tu-160 in a Tu-22M aircraft. When they qualify, they can adopt its nickname 'White Swan' (due to its white finish and manoeuvrability).

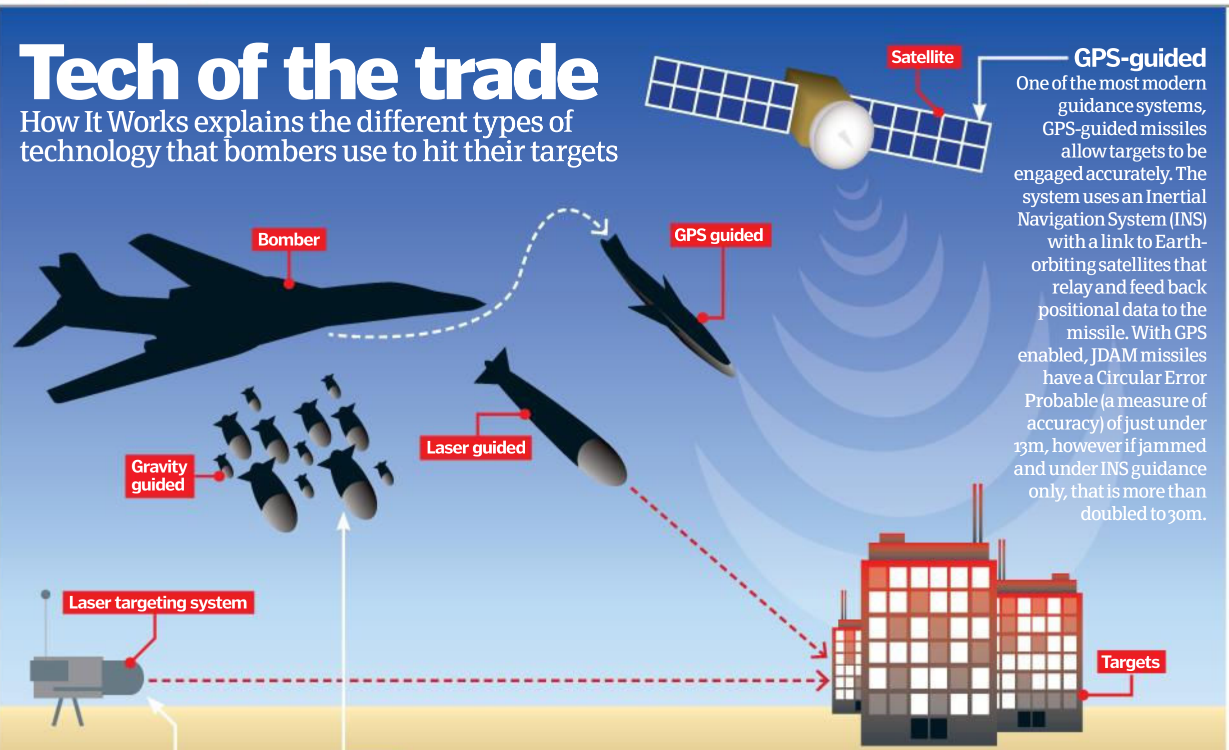
Etymology

5 The etymology of 'bomb' comes from the French 'bombe', which comes from the Italian 'bomba', which comes from the Latin 'bombus', which stems from Ancient Greek.

DID YOU KNOW? *A single B-1B Lancer costs $283 million to produce*

Tech of the trade

How It Works explains the different types of technology that bombers use to hit their targets



GPS-guided
One of the most modern guidance systems, GPS-guided missiles allow targets to be engaged accurately. The system uses an Inertial Navigation System (INS) with a link to Earth-orbiting satellites that relay and feed back positional data to the missile. With GPS enabled, JDAM missiles have a Circular Error Probable (a measure of accuracy) of just under 13m, however if jammed and under INS guidance only, that is more than doubled to 30m.

Laser-guided
Laser-guided systems rely on targets to be 'lit up' with a Laser Target Designator (LTD) system. Usually ground-based, they involve a laser designator being pointed at target. The missile's infrared seeking unit locates the designation and adjusts its trajectory.

Gravity guided
Bombs are dropped free-fall, relying on gravity and aircraft co-ordinates to strike. Due to their relative inaccuracy, gravity-guided bombs tend to be released in clusters to maximise the chance of a successful strike. Dependent on aircraft speed and altitude, these bombs can be fitted with various tails and retarders to speed up/slow down fall time.

A B-1B taking off at the Royal International Air Tattoo. Note the firing General Electric F101-GE-102 augmented turbofans

© USAF

The B-1 is capable of being refuelled during flight for an extended patrol and bombing runs

The statistics…

B-1B Lancer

Crew: 4

Length: 44.5m (146ft)

Wingspan: 41.8m (137ft)

Height: 10.4m (34ft)

Loaded weight: 148,000kg (326,000lb)

Powerplant: 4 x general electric F101-GE-102 augmented turbofans

Max speed: Mach 1.25 (830mph/1,340kmh)

Range: 11,998km (7,456 miles)

Max altitude: 18,000m (60,000ft)

Hardpoints: 9 (6 external, 3 internal)

The two current foremost examples of these bombers are the US B-1B Lancer and the Russian Tupolev Tu-160. These were designed concurrently to be machines that could, on demand, travel long distances quickly, slip under early-warning radar and engage military targets with smart munitions – bombs that could be launched from hundreds or thousands of miles out and guided to their target by internal inertial navigation units and auxiliary information delivery systems. These strategic bombers, packing gravity, laser and GPS-guided munitions (see 'Tech of the trade' boxout) render anti-aircraft gun placements useless, and avoid surface-to-air missiles by flying at altitudes northwards of 60,000 feet.

The B-1B Lancer is built around a blended wing body configuration, with variable-sweep wings, four turbofan engines and triangular fin control composite surfaces. Its wings can be varied by the pilot between 15 to 67.5 degrees, with the former being used for takeoff and landing as well as high-altitude cruising, and the latter being used for high subsonic and supersonic flight. Stability is ensured – a problem due to its large size and weight – by triangular fin control canards located by the B-1's nose. These are

WEAPONS OF WAR
B-1B Lancer

© BrokenSphere

MK-82
A low-drag, general-purpose, unguided bomb. It is a stock munition for a variety of US aircraft, including the B-1B Lancer, which can carry northwards of 84 units. The MK-82 weighs 500 pounds and measures 222cm (87.4 in) long and 27cm (10.75 in) in diameter. Each unit has a 192lb filling of tritonal – 80 per cent TNT, 20 per cent aluminium powder – which can be fitted with fin kits, fuses and retarders to suit each mission.

© Damon Moritz-USN

AGM-154
A medium-range launch-and-leave missile, the AGM-154 allows bombing aircraft to engage defended targets from outside the range of conventional anti-air weaponry. The missile, which measures 406cm (160 in) long by 33cm (13 in) in diameter, is guided by a Global Positioning System of satellites with an internal Inertial Navigation System. This twin system allows for enhanced accuracy and release range.

© USAF

GBU-39
The GBU-39 is a small-diameter bomb weighing little more than 250 pounds that, dependent on specification, can be guided to a target via a GPS-aided inertial navigation system (as with the AGM-154), or by a thermal seeker with integrated auto target recognition. The thermal seeker works by tracking the electromagnetic radiation of a target with an IR sensor (infrared), before visibly zeroing in on the heat signature once launched.

> "The Tupolev Tu-160 is larger and heavier than the B-1"

controlled by the Lancer's Structural Mode Control System (SMCS), which automatically rotates the canards to counteract turbulence. In addition, to aid the minimisation of its radar cross section (RCS), the B-1 is installed with serpentine air intake ducts and fixed intake ramps. These, while limiting its top speedm deflect and shield radar emissions from the highly reflective engine compressor blades. This technology, in partnership with the use of radar-absorbent material in its airframe and skin, grant the B-1 a RCS 1/50th of that of the equally massive B-52 Stratofortress.

The Tupolev Tu-160, in contrast, is larger and heavier than the B-1, however it shares many of the same features and design choices. First, the aircraft sports a blended wing profile with sweep-enabled wings that can be swept by the pilot between 20 and 65 degrees. It is also powered by four Kuznetsov NK-321 afterburning turbofan engines, the most powerful array fitted to any combat aircraft. These, in partnership with variable air intakes, grant it a B-1 topping max speed of Mach 2.05 (1,380mph), although its radar signature is larger as a result. Due to its larger size, the 160 also has a greater weapons load capacity than the B-1, with twin internal rotary launchers capable of holding and launching 40,000kg of munitions. In addition, nuclear and conventional armaments can be carried (see the 'Weapons of war – Tu-160' boxout) dependent on mission parameters. Finally, as with the B-1, the Tu-160 is fitted with a probe and drogue in-flight refuelling system, allowing it to remain airborne for extensive periods.

Both of these aircraft have demonstrated their awesome ability since their introduction to the skies, with numerous sorties undertaken and many notable records broken. Most recently the USAF deployed a series of B-1s as part of Operation Odyssey Dawn, the international military operation in Libya, to prevent Muammar Gaddafi's forces from bombing rebel forces, striking a multitude of undisclosed military targets.

WEAPONS OF WAR
Tu-160

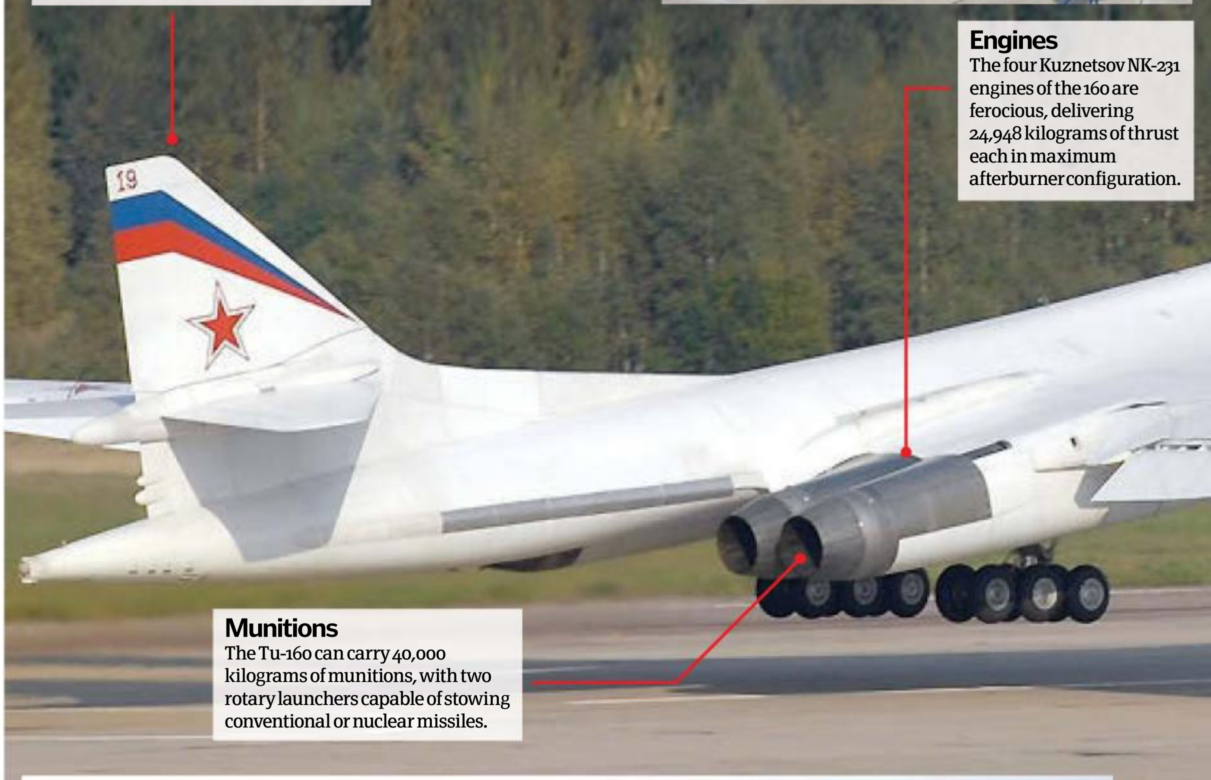
Kh-55
A Soviet/Russian air-launched cruise missile capable of carrying a conventional or nuclear warhead, the Kh-55 is the primary missile system of the Tu-160. It has a range of 3,000km and a top speed of Mach 0.78, while thanks to its Inertial Navigation System with a Doppler radar mapping service, has a strike accuracy of within 9m. To achieve its range the Kh-55 is powered by an R95-300 turbofan engine, activated along with swept wings once launched. Missiles are stored in a rotary launcher, which rotates missiles like a six-shooter's bullet chamber until in optimal position.

Kh-15
The Kh-15 is a short-to-medium range missile that can be equipped with a nuclear or conventional warhead. 4.5m (15ft) long by 5.5m (17.9 ft) in diameter and with a range of 300km (186 miles), the missile is guided by inertial navigation, active radar or anti-radiation – the latter a system that detects and homes in on an enemy's radio emissions. Central to the Kh-15's design is its post-launch velocity accumulation flight path, climbing to 130,000ft before diving at a speed of Mach 5 (almost 4,000mph) onto its target.

Tu-160
The world's largest variable-sweep aircraft, the Tu-160 is a supersonic strategic missile carrier like no other

A Tu-160 is exhibited to the general public during a Russian airshow

© Yevgeny Pashnin



Electronics
In terms of electronics, the 160 utilises a Obzor-K attack radar in a dielectric radome, a Sopka terrain-following radar and electro-optical bombsight.

Engines
The four Kuznetsov NK-231 engines of the 160 are ferocious, delivering 24,948 kilograms of thrust each in maximum afterburner configuration.

Munitions
The Tu-160 can carry 40,000 kilograms of munitions, with two rotary launchers capable of stowing conventional or nuclear missiles.

The Tu-160 has the heaviest take-off weight of any combat aircraft

© Sergey Krivchikov-Russian AviaPhoto Team

DID YOU KNOW? On 10 June, 2010, two Tu-160s carried out a world-record 23-hour non-stop patrol

President of Russia Vladimir Putin sits in the cockpit of a Tu-160

Cockpit
The Tu-160 is operated by a crew of four, with a pilot, co-pilot, weapons systems operator and defensive systems operator on board each sortie.

ВАЛЕНТИН БЛИЗНЮК

Wings
The Tu-160 features variable geometry wings, with sweep selectable from 20 to 65 degrees. It also employs a blended wing profile.

The statistics…

© Presidential Press and Information Office

Tu-160

Crew: 4

Length: 54.10m (177ft)

Wingspan: 55.70m (189ft)

Height: 13.10m (43ft)

Loaded weight: 267,600kg (589,950lb)

Powerplant: 4 x Samara NK-321 turbofans

Max speed: Mach 2.05 (1,380mph/2,220kmh)

Range: 12,300km (7,643 miles)

Max altitude: 15,000m (49,200ft)

Hardpoints: 4

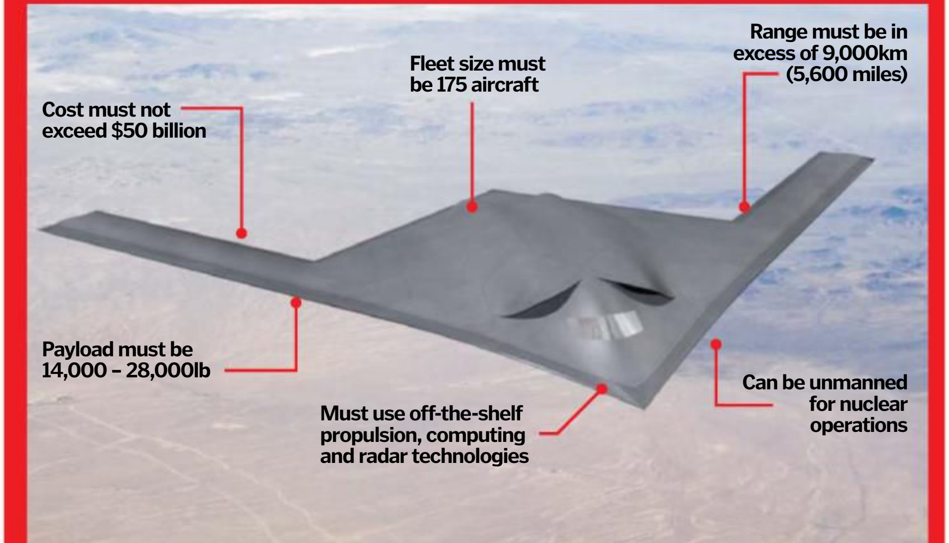
A series of Mk-82 bombs explode in quick succession during a test bombing run

A collection of laser-guided bombs connect with Raynham island, Queensland, Australia

Bombers of the future

New machines to be ready for 2018

Despite current bombers' advanced technology and weapons, the US Air Force is now developing its next-generation bomber, scheduled to enter service by 2018. Codenamed the '2018 Bomber', the new system is poised to harness the stealth-orientated strike capabilities of the F-35 fighter jet but extend them into an aircraft with long-range operability. With a design brief that the new bomber must be capable of strategic bombing, tactical bombing and prompt global strike roles, as well as having the ability to carry nuclear weapons, a host of companies including Lockheed Martin, Boeing and Northrop Grumman are working towards a prototype being delivered for 2016. See below for the 2018's design goals as of January 2011:


Cost must not exceed $50 billion
Fleet size must be 175 aircraft
Range must be in excess of 9,000km (5,600 miles)
Payload must be 14,000 – 28,000lb
Must use off-the-shelf propulsion, computing and radar technologies
Can be unmanned for nuclear operations

A Boeing-produced render of a potential design for the 2018 Bomber. Note its stealth-orientated shape

© Boeing

F-35 AND THE FUTURE FIGHTERS

Legacy aircraft worldwide are being blown out of the skies by a formation of revolutionary multi-role fighter jets, offering all-round air supremacy and a lethal barrage of explosive new technology

5 TOP FACTS
F-35 Lightning II

Birth
1 The F-35 was born out of the joint strike fighter (JSF) programme, which was initiated to create an aircraft that would replace the F-16, A-10, F/A-18 and AV-8B tactical fighter jets.

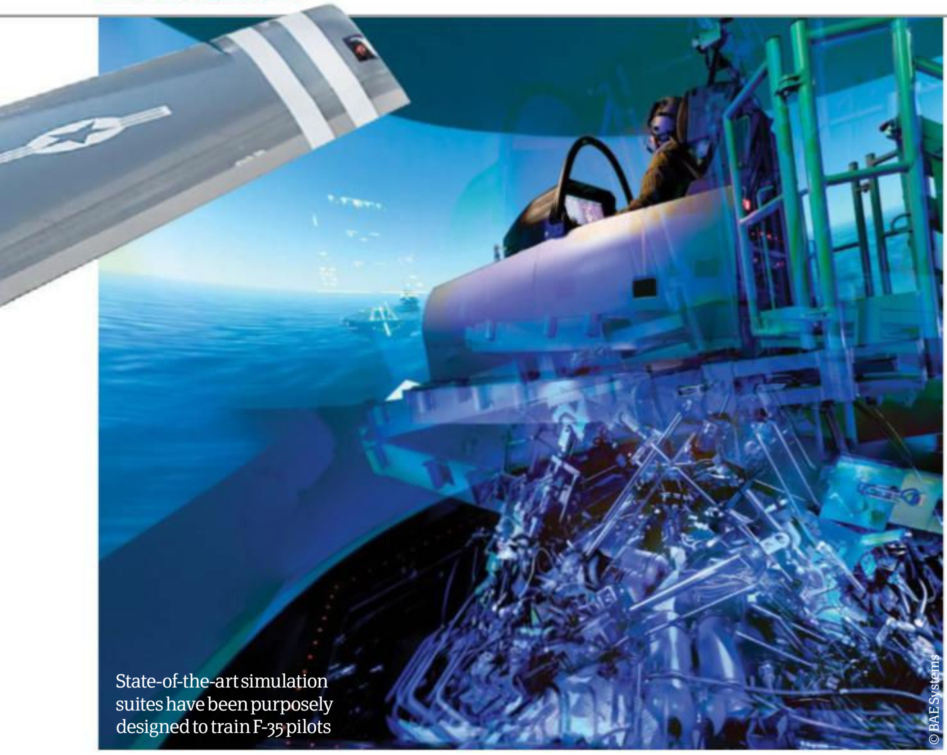
X-35
2 The prototype F-35 was the Lockheed Martin X-35, which narrowly beat a rival design from Boeing (X-32), despite both aircraft exceeding or meeting the JSF requirements.

DoD
3 Interestingly, the F-35 designation of the Lightning II is out of sequence with standard DoD numbering. It was supposed to be named the F-24 instead.

Alliance
4 There are eight global partners in the F-35's development along with the USA: the UK, Italy, the Netherlands, Australia, Canada, Denmark, Norway and Turkey.

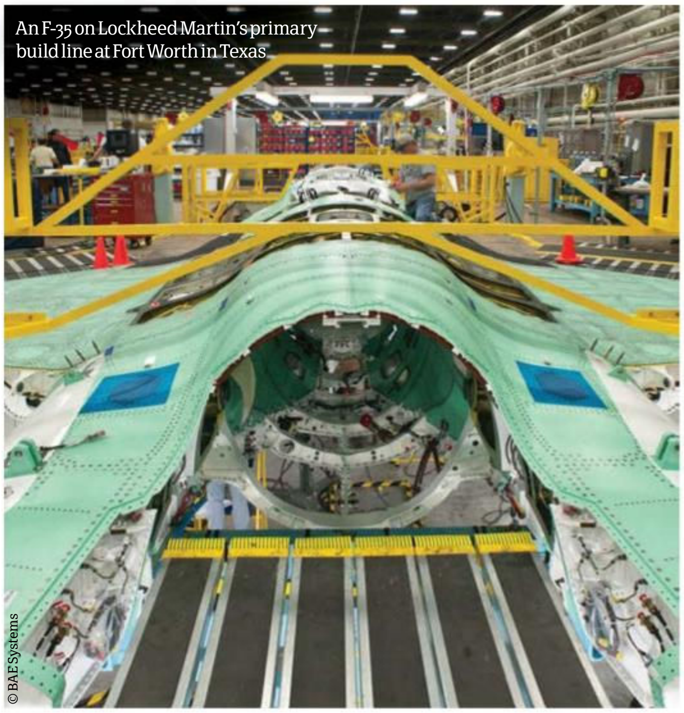
LiftSystem
5 The STOVL variant of the F-35 Lightning II uses the Rolls-Royce LiftSystem, an innovative propulsion system that allows for the main engine exhaust to be redirected for vertical lift.

DID YOU KNOW? *Total development costs of the F-35 Lightning II are estimated to have run to $40 billion*


State-of-the-art simulation suites have been purposely designed to train F-35 pilots

© BAE Systems

> "Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy and bismaleimide"


An F-35 on Lockheed Martin's primary build line at Fort Worth in Texas

© BAE Systems

F-35 Lightning II

Put simply, the most versatile, deadly and technologically advanced fighter jet in the world

The latest and greatest 'black project' from Lockheed Martin's Skunk Works – technically referred to as the Advanced Development Programs (ADP) unit, a classified division of the company unrestrained by bureaucracy – the F-35 Lightning II is the most advanced fighter jet on Earth. It's the first and only stealthed, supersonic, multi-role fighter.

Born out of a demand to dominate the fluid 21st-century battlefield, replacing a plethora of legacy aircraft such as the F-16 and A-10 Thunderbolt II, the F-35 is rewriting the rulebook on aircraft design, capable of performing almost any possible role imaginable today – be that strike, support or reconnaissance – with greater efficiency than any other aircraft made to date. The cost of this performance? £89m ($139m) per plane.

So what does all that cash actually buy you? To start, the most powerful powerplant ever fitted to a fighter aircraft. The F-35, across all its three variants – read: F-35A, F-35B and F-35C, differentiated largely by takeoff mechanism – is fitted with a Pratt & Whitney F135 afterburning turbofan jet engine, which delivers a mighty 19,500 kilograms (43,000 pounds) of thrust and grants a sound-shattering top speed of over 1,930 kilometres (1,200 miles) per hour; that's over Mach 1.6 or, to put it another way, infinitely faster than your gran's Mini Metro!

The cash, which is being dropped in large quantities by the States, as well as eight other global partners including the United Kingdom – which is set to deploy the aircraft on its new Queen Elizabeth-class aircraft carriers – also purchases the operator one of the most advanced aircraft structures in existence. Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy and bismaleimide (BMI), to produce a framework unrivalled in lightness and strength, as well as heavily integrating epoxy glass resin to maximise aerodynamics. In terms of skin and coatings, each F-35 aircraft sports a radar cross-section (ie radar signature) the size of a golf ball thanks to the heavy implementation of fibre-mat over the fuselage.

The cockpit is also state of the art, delivering a full-panel-width, panoramic glass cockpit display as well as a host of bleeding-edge avionics and sensors such as the Northrop Grumman AN/APG-81 AESA radar and electro-optical targeting system (EOTS). Further, much of the cockpit has been optimised for speech-recognition interaction, allowing the pilot to control many parts of the jet by voice alone.

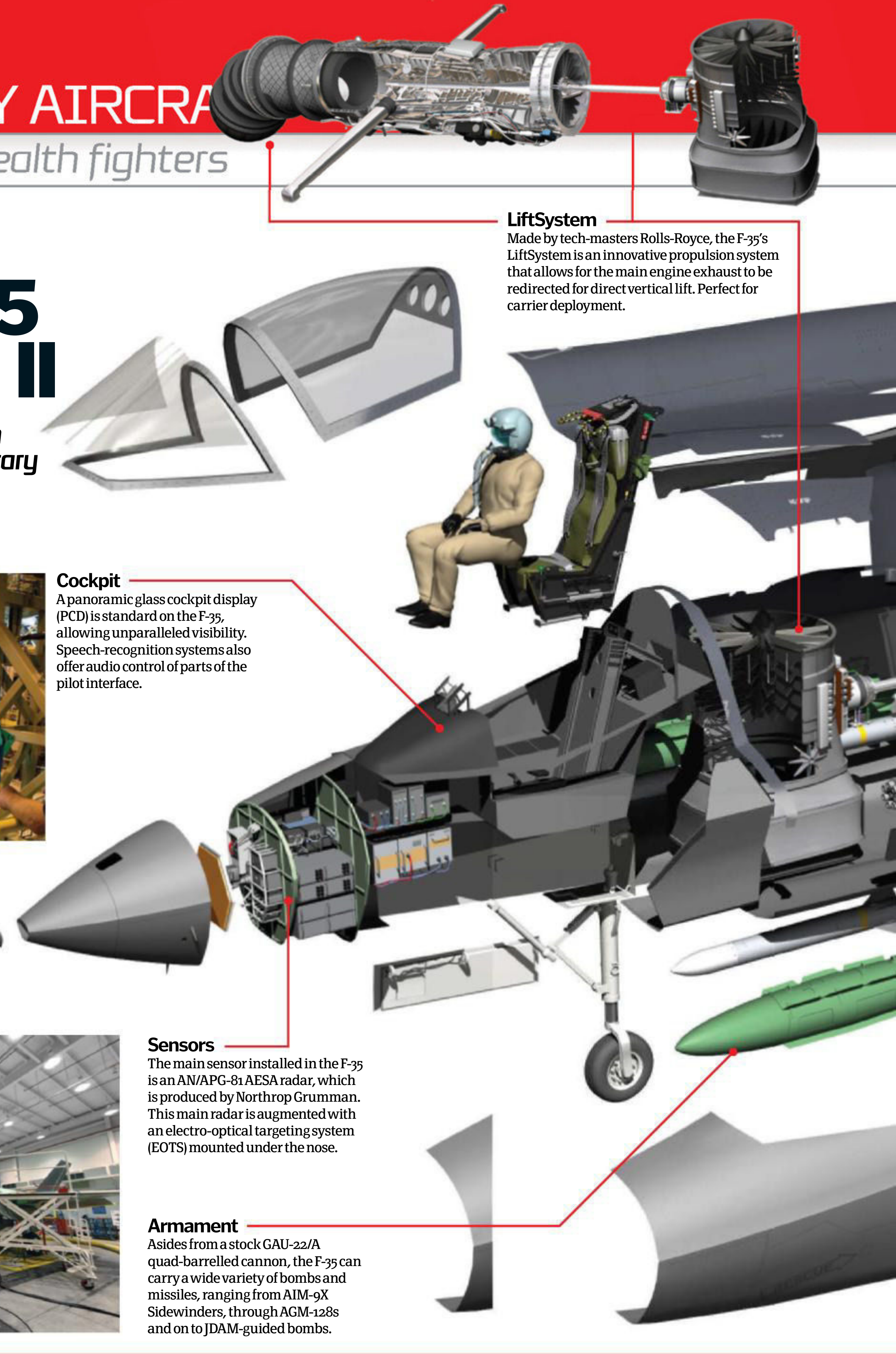
Of course, the main attraction of the Lightning II is its diverse armaments – the equipment that transforms it from technical marvel into a master of destruction. You want air-to-air prowess? You've got it, with the F-35 capable of launching AIM-120 AMRAAMs, AIM-9X Sidewinders, IRIS-Ts and the futuristic beyond-visual-range MBDA Meteor. For maximum air-to-ground penetration, take your pick from AGM-154 JSOWs, SOM Cruise Missiles and Brimstone anti-tank warheads. Even if you want to engage marine-based targets the F-35 delivers the goods, capable of launching the new anti-ship Joint Strike Missile (JSM). Throw in a raft of other munitions, including the Mark 80 series of free-fall bombs, Mk.20 Rockeye II cluster bomb, the Paveway series of laser-guided bombs and even, in DEFCON 1 situations, the B-61 nuclear bomb and you have one extremely versatile and deadly feat of aviation.

The rate of climb of the F-35 is currently classified

© BAE Systems

Anatomy of the F-35 Lightning II

How It Works breaks down this awesome piece of military engineering to see what makes it so advanced



LiftSystem
Made by tech-masters Rolls-Royce, the F-35's LiftSystem is an innovative propulsion system that allows for the main engine exhaust to be redirected for direct vertical lift. Perfect for carrier deployment.

© BAE Systems

Cockpit
A panoramic glass cockpit display (PCD) is standard on the F-35, allowing unparalleled visibility. Speech-recognition systems also offer audio control of parts of the pilot interface.

© BAE Systems

Sensors
The main sensor installed in the F-35 is an AN/APG-81 AESA radar, which is produced by Northrop Grumman. This main radar is augmented with an electro-optical targeting system (EOTS) mounted under the nose.

Armament
Asides from a stock GAU-22/A quad-barrelled cannon, the F-35 can carry a wide variety of bombs and missiles, ranging from AIM-9X Sidewinders, through AGM-128s and on to JDAM-guided bombs.

History of multi-role fighter jets

The F-35 is the culmination of more than 30 years of development into producing a single, king-of-all-trades fighter plane

1979 Panavia Tornado

The first multi-role fighter to be produced, the Panavia Tornado – across its three variants (each providing differing abilities) – offered its owner the best of striker, bomber, interceptor and reconnaissance aircraft.

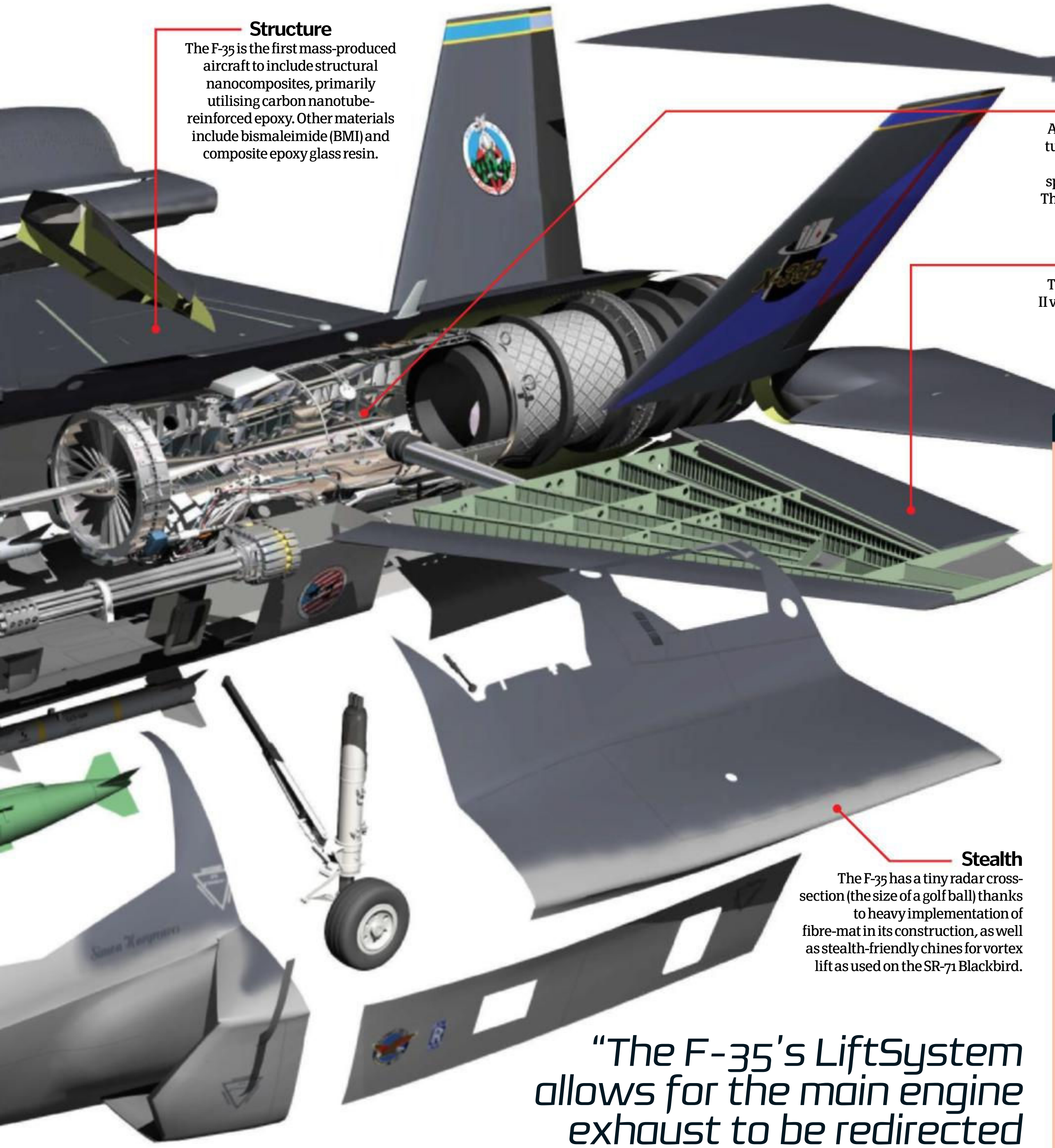
1983 McDonnell Douglas F/A-18 Hornet

Maybe the most recognisable multi-role fighter until the F-22, the Hornet was an all-weather, carrier-capable fighter specialising in short/medium-range bombing ops.

1988 JAS-39 Gripen

Another early delta-wing, multi-role fighter, the Gripen was designed to be incredibly lightweight for a fighter and sported impressive air-to-ground bombing capabilities. It has recently been upgraded for continued use.

DID YOU KNOW? The F-35 has the capability to carry and launch a B-61 nuclear bomb



Structure

The F-35 is the first mass-produced aircraft to include structural nanocomposites, primarily utilising carbon nanotube-reinforced epoxy. Other materials include bismaleimide (BMI) and composite epoxy glass resin.

Powerplant

A Pratt & Whitney F135 afterburning turbofan delivers 19,500kg (43,000lb) of thrust to the F-35, allowing a top speed of over 1,930km/h (1,200mph). The engine is the most powerful ever installed in a fighter aircraft.

Wings

The total wing area of the Lightning II varies dependent on configuration, with the CTOL and STOVL variants sporting 43m² (460ft²) and the CV variant 62m² (668ft²).

Stealth

The F-35 has a tiny radar cross-section (the size of a golf ball) thanks to heavy implementation of fibre-mat in its construction, as well as stealth-friendly chines for vortex lift as used on the SR-71 Blackbird.

> "The F-35's LiftSystem allows for the main engine exhaust to be redirected for direct vertical lift"

The statistics…

F-35A

Crew: 1

Length: 15.7m (51.4ft)

Wingspan: 10.7m (35ft)

Height: 4.3m (14.2ft)

Weight: 13,300kg (29,300lb)

Powerplant: 1 x Pratt & Whitney F135 afterburning turbofan

Dry thrust: 125kN (28,000lbf)

Thrust with afterburner: 191kN (43,000lbf)

Max speed: Mach 1.6 (1,930km/h; 1,200mph)

Max range: 2,220km (1,379mi)

Max altitude: 18,288m (60,000ft)

Thrust/weight: 0.87

g-limit: +9 g

Guns: 1 x General Dynamics GAU-22/A Equalizer 25mm four-barrelled Gatling cannon

Hardpoints: 6 x external pylons, 4 x internal pylons

Max payload: 8,100kg (18,000lb)

Armament: Air-to-air, air-to-ground, anti-ship

© MOD Czech Republic

1996 Sukhoi Su-30

© Sergey Krivchikov

Envisioned as a fighter jet with excellent air-to-surface deep interdiction prowess (the ability to strike hostile targets at extreme range from friendly forces), the Russian Su-30 typifies multi-role designs from the mid-Nineties.

2000 Dassault Rafale

Marketed by Dassault as an 'omnirole' jet, the Rafale was an agile delta-wing fighter, specialising in air supremacy. A collapse in a multi-nation agreement, however, led it to be used for other roles by France and India.

2005 Lockheed Martin F-22 Raptor

Originally conceived as an air superiority fighter, the F-22 evolved over time into a multi-role jet, capable of ground attack and electronic warfare roles thanks to its extremely low radar cross-section.

© Rob Shenk

© Alex Pang

> "Typhoon pilots are now linked to their aircraft by 'electronic umbilical cords'"

According to government officials, the T-50 will have a low radar cross-section and have the ability to supercruise (perform sustained supersonic flight)

© Maxim Maksimov

Sukhoi T-50

Russia's hottest jet project currently in development, the highly classified Sukhoi T-50 is a fifth-generation multi-role fighter designed to deliver awesome long-range strike capabilities

Arguably the main competitor to the F-35 Lightning II, the Russian-made Sukhoi T-50 is an extremely advanced, twin-engine, multi-role jet fighter that, aside from being a top-level black project (in other words, highly hush-hush), promises to deliver an insane top speed, range and payload.

Power, which is titanic – 267 kilonewtons (66,000 pounds-force) of thrust on afterburner – comes courtesy of two Saturn 117 turbofan jet engines. The thrust has been drastically increased since the previous AL-31 powerplant and this not only allows the T-50 to easily surpass Mach 2 (a top speed of 2,500 kilometres, or 1,500 miles, per hour) but also supercruise – continuously fly at supersonic speeds without engaging the afterburner.

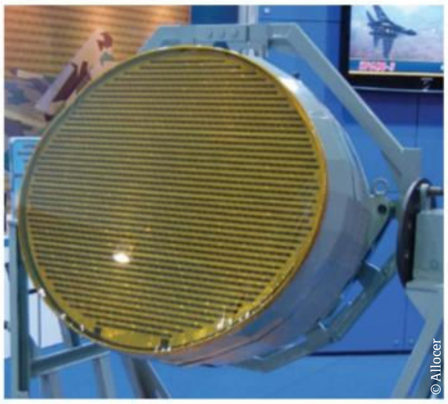
The reason for the twin-engine setup, as well as the supersized fuel tanks, is to help fulfil the T-50's design focus to specialise in long-range interdiction operations (striking at enemy targets that are located at a great range from allied forces). This is a core competency for modern Russian military bombing aircraft due to the size of the country and the great distances between stopover points.

Avionics are handled by an integrated radar complex, which includes three X-band active electronically scanned array (AESA) radars mounted to the front and sides of the aircraft, an infra-red search and track (IRST) system, as well as a pair of L-band radars on the wing leading edges, which are specially designed to detect very low observable (VLO) targets.

In terms of firepower, the production variant of the T-50 will boast up to two 30-millimetre cannons, as well as a mix of Izdeliye 810 extended-beyond-visual-range missiles, long-range missiles, K74 and K30 air-to-air short-range missiles and two air-to-ground missiles per weapons bay. Free-fall bombs can also be carried – with a limit of up to 1,500 kilograms (3,300 pounds) per bomb bay – as well as various anti-AWACS (airborne warning and control system) armaments, such as the RVV-BD variant of the Vympel R-37.

Currently only a handful of T-50s have been produced and flown, however it is expected that throughout its 35-year life span beginning in 2016, more than 1,000 jets will be made, each unit costing between £31-36m ($48-57m).

The NIIP AESA radar as will be used on the production variant of the T-50


© Allocer

As well as air-to-air roles, the Typhoon can adapt to air-to-ground operations, delivering GBU-16 Paveway II bombs

The statistics…

© Dmitry Pichugin

Sukhoi T-50

Crew: 1

Length: 19.8m (65.9ft)

Wingspan: 14m (46.6ft)

Height: 6.05m (19.8ft)

Weight: 18,500kg (40,785lb)

Powerplant: 2 x AL-41F1 afterburning turbofans

Max speed: Mach 2+ (2,500km/h; 1,560mph)

Max range: 5,500km (3,417mi)

Max altitude: 20,000m (65,600ft)

Rate of climb: Classified

Thrust/weight: 1.19

g-limit: Classified

Guns: 2 x 30mm cannons

Hardpoints: 6 x external pylons, 4 x internal pylons

Armament: Air-to-air, air-to-ground, anti-ship

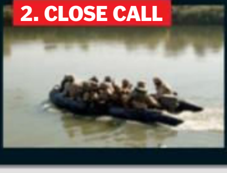
1. ELECTRIC

© Allocer

Electronic warfare

Some jets use specialised equipment to control, disrupt or attack enemy targets with a host of cutting-edge electromagnetic weaponry.

2. CLOSE CALL



Close air support

Supporting ground troops with air action despite their close proximity. Achieved with fixed-wing or rotary aircraft.

3. LONG DISTANCE

Air interdiction

This role involves using aircraft to attack tactical ground targets that are not currently in close proximity to ground forces but located at a considerable range.

DID YOU KNOW? *The Sukhoi T-50 is expected to be renamed to the Sukhoi PAK FA when it is officially launched in 2016*

Eurofighter Typhoon

The Typhoon is one of the most adaptable multi-role fighters in operation today and has recently been upgraded to deliver enhanced air superiority and all-round lethality in its combat operations over the next decade

The Eurofighter Typhoon is currently one of the most agile aircraft in the world. It is so agile, in fact, that attempting to blow it out the skies is like trying to make a mile-long sniper shot in high wind. Why? It was built to be fundamentally aerodynamically unstable and, if it were not for its advanced fly-by-wire control system generating artificial stability, would be too much for even the most experienced pilot to handle. This instability, however, allows for pilots to perform some physics-bending manoeuvres at just plain stupid speeds – read: upwards of Mach 2 – delivering them a combative edge and helping to ensure total air supremacy.

Of course, agility alone can only take you so far – especially so when the hardware needs to fulfil almost every airborne military role imaginable. Good job then that the Typhoon can carry an abundance of weapons. You need to go toe-to-toe with enemy fighters in an air-to-air combat dogfight? No problem, take your pick from Sidewinder, ASRAAM and AMRAAM air-to-air missiles. Need to undertake a bombing run through hostile territory? Well, the Typhoon's 13 hardpoints allow for Maverick, HARM and Taurus munitions to be smartly delivered (via laser-guiding and GPS) with ice-cold efficiency. Need to disrupt a hostile target's comms network through a tactical electronic warfare strike… You get the point.

Supporting this awesome arsenal is an upgraded weapons system, which has been designed to unite the pilot and hardware like never before. Typhoon pilots are now linked to their aircraft by an 'electronic umbilical cord', which extends from a comms-optimised helmet directly into the jet's system. This not only allows images and videos of notable contextual information to be directly fed to the helmet's visor for immediate consultation by the pilot, but also enables special nodules on the helmet to be tracked by fixed sensors in the aircraft's cockpit. As such, wherever the pilot's head moves, the aeroplane knows exactly where they are looking and can automatically prep weapon stores dependent on the perceived level of threat.

Any future fighter though also needs to be prepared to defend itself against a barrage of smart munitions, which again – thanks to the Typhoon's perpetual evolution – the hardware delivers in spades. The entire jet is protected by a high-integrated defensive aids sub-system (DASS), also nicknamed Praetorian. Praetorian consists of a wide array of sensors and electronic/mechanical systems – detection is handled by both a radar warning receiver and laser warning receiver – that automatically track and then respond to both air-to-air and surface-to-air threats. The plane can respond by releasing chaff (eg small bits of aluminium or metallised glass, etc), flares and electronic countermeasures (ECM), as well as by releasing a towed radar decoy (TRD).

As of October 2011, 300 Typhoons are recorded to be in operation worldwide with over 170 aircraft on order.

> *"The Typhoon's 13 hardpoints allow multiple munitions to be smartly delivered with ice-cold efficiency"*

The RAF received its first multi-role capable Typhoons in March 2007

5x Typhoon images © BAE Systems

A Typhoon undertakes a low pass at high speed

© BAE Systems

The statistics…

Eurofighter Typhoon

Crew: 1

Length: 16m (52.4ft)

Wingspan: 11m (35.9ft)

Height: 5.3m (17.3ft)

Weight: 11,150kg (24,600lb)

Powerplant: 2 x Eurojet EJ200 afterburning turbofans

Dry thrust: 60kN (13,000lbf) each

Thrust with afterburner: 89kN (20,000lbf) each

Fuel capacity: 4,500kg (9,900lb) internal

Max speed: Mach 2+ (2,495km/h; 1,550mph)

Max range: 3,790km (2,350mi)

Max altitude: 19,810m (64,990ft)

Rate of climb: >315m/s (62,000ft/min)

Thrust/weight: 1.15

g-limit: +9/-3 g

Guns: 1 x 27mm Mauser BK-27 revolver cannon

Hardpoints: 13 (8 x under-wing, 5 x under-fuselage)

Max payload: 7,500kg (16,500lb)

Armament: Air-to-air, air-to-ground, anti-ship

Commercial

76 **Commercial drones**
How drones and unmanned aerial vehicles (UAVs) will change your life

84 **How to build a plane**
How many people and hours does it take to build a passenger jet?

88 **The luxury of the Lineage 100 jet**
Fly in the most luxurious hotel in the sky for only a few million dollars

90 **Largest passenger jet**
Developing the largest and most expensive passenger plane in the world

92 **The new Concorde**
Will this incredible aircraft soar once again?

94 **On board Air Force One**
Transporting the US President requires an aircraft that can respond to varied situations

96 **Solar-powered aircraft**
Take a close look at the flying machines that are fuelled only by the Sun

98 **Hot air balloons**
How do air balloons take off and land safely using the power of physics?

100 **On board a cargo plane**
Pinpointing what an aircraft needs to get the job of carrying cargo done

102 **Boeing 787 Dreamliner**
This new commercial jetliner boasts next-gen features that showcase the future of flying

106 **Gliders**
Find out what it is that keeps these gliders in the air

107 **Inside a blimp**
These graceful forms of transport are kept afloat by gas-filled ballonets

108 **Inside Air Force One**
What really goes on inside the president of the United States' private jet?

110 **How to fly a helicopter**
What does it take to become a helicopter pilot? Find out on this page

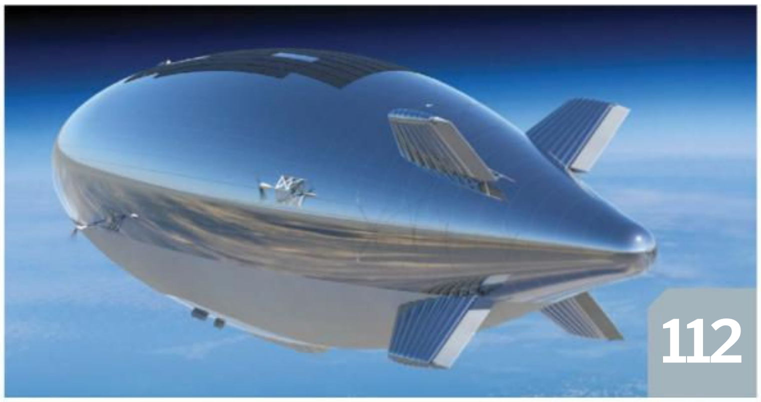
111 **The AirBoard**
Meet the AirBoard, the smallest one-person aircraft in the world

112 **How next-generation airships work**
Climb aboard these ultra-light giants for a journey into the future of flight

90
A380
A380 AIRBUS

108

111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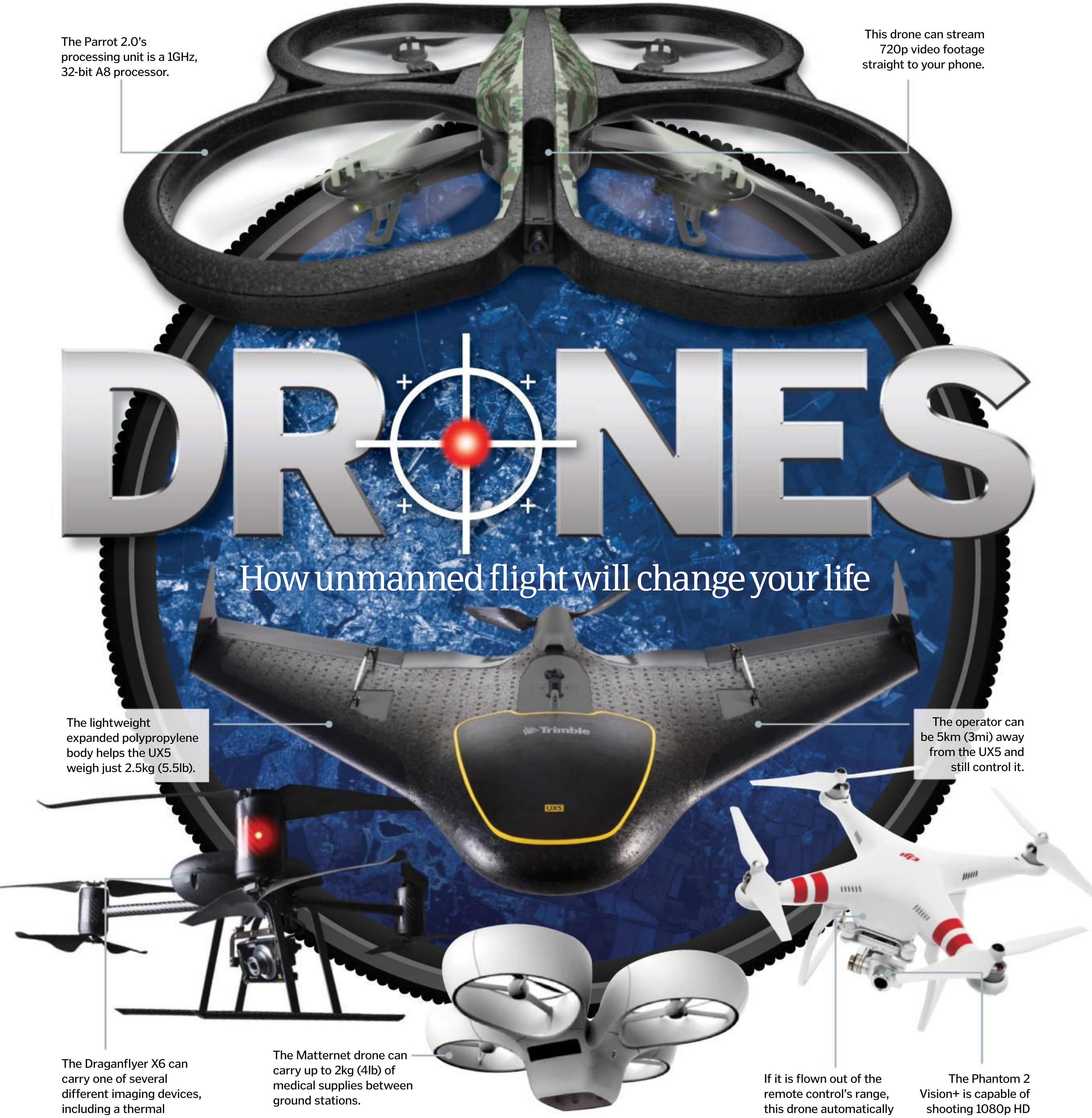
DRONES

How unmanned flight will change your life



The Parrot 2.0's processing unit is a 1GHz, 32-bit A8 processor.

This drone can stream 720p video footage straight to your phone.

The lightweight expanded polypropylene body helps the UX5 weigh just 2.5kg (5.5lb).

The operator can be 5km (3mi) away from the UX5 and still control it.

The Draganflyer X6 can carry one of several different imaging devices, including a thermal imaging camera.

The Matternet drone can carry up to 2kg (4lb) of medical supplies between ground stations.

If it is flown out of the remote control's range, this drone automatically returns home.

The Phantom 2 Vision+ is capable of shooting 1080p HD video at 30fps.

5 TOP FACTS
Drone tech

Also known as

1 The name drone refers to any aircraft without a pilot on board. They are also known as unmanned aerial vehicles (UAVs), remote piloted aircraft (RPA) or unpiloted air systems (UAS).

Future swarms

2 There are over 4,000 different UAVs in circulation on the global market and the FAA estimates that as many as 7,500 small commercial drones could be operational in US airspace by 2020.

Friendly drones

3 In Britain, manufacturers have suggested painting drones in bright colours as a way to make them appear friendlier and less reminiscent of warzones.

The first drone

4 The first powered UAV was the "Aerial Target" invented by Archibald Montgomery Low in 1917. It was launched using compressed air from the back of a lorry.

Control methods

5 Drones can be controlled in one of two ways; either autonomously by an on-board computer, or remotely by a pilot on the ground.

DID YOU KNOW? *The number of organisations allowed to use drones in the UK went up 80 per cent from start to end of 2014*

Drones offer a whole new perspective on video recording and photography

Drones are being used in air forces around the world, but the future is looking much more varied for the remote controlled aircraft. There is a fast-growing industry of autonomous flight that can both help and entertain the world, from rescuing people at sea to recording awe-inspiring aerial videos.

Disaster relief, for example, is a major area where drones can make an incredible difference. They can fly over the scene of an earthquake, nuclear meltdown or bomb site and capture high-resolution pictures or video to help the team on the ground organise a rescue or clean-up mission. Drones such as the Trimble UX5 could be of enormous benefit as the 2.4-gigahertz modems in the craft and the tablet can communicate over a distance of five kilometres (3.1 miles), enabling mapping to take place with the pilot nowhere near potentially dangerous rubble and aftershocks.

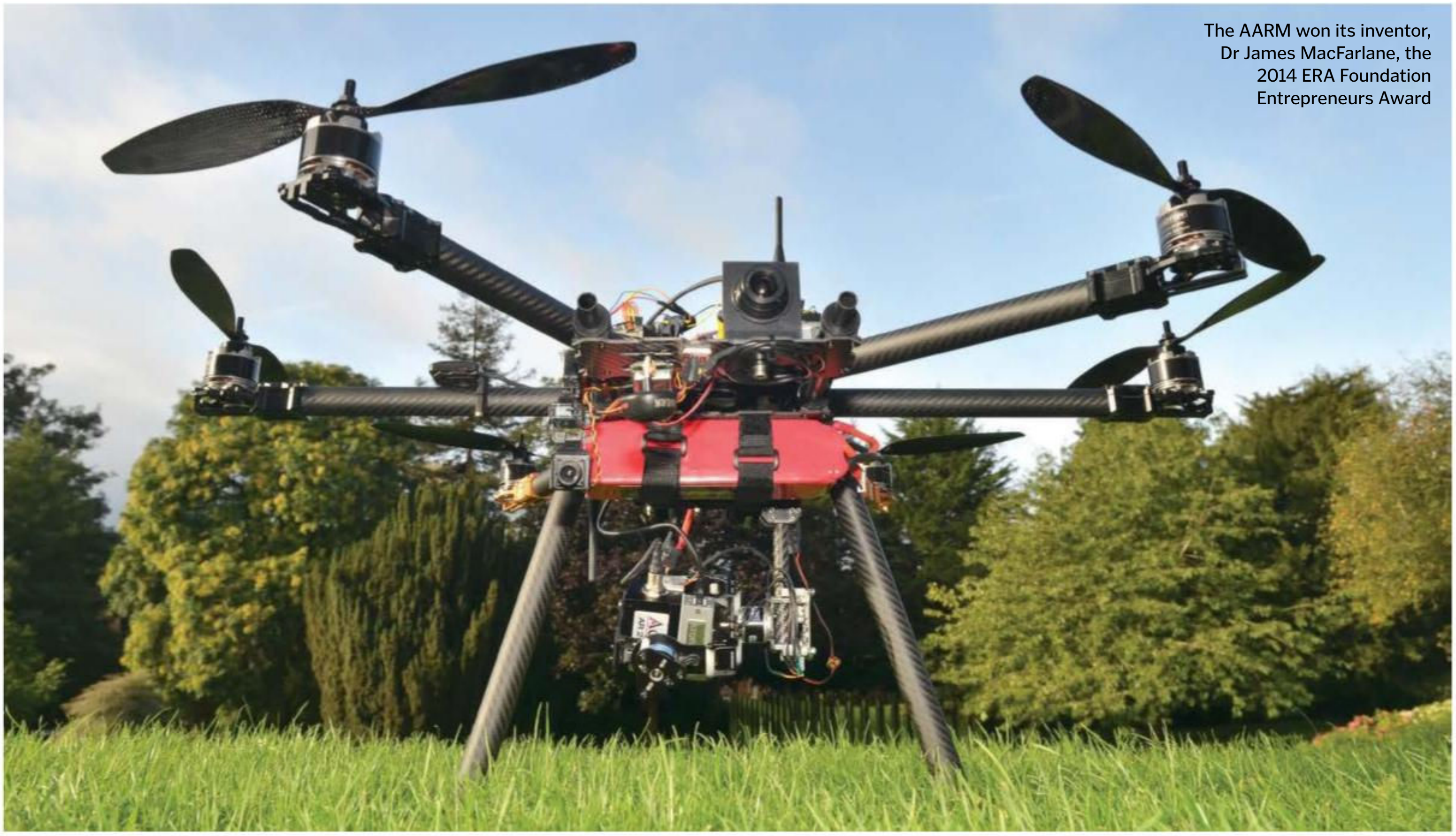
When the Fukushima nuclear power plant malfunctioned in March 2011, clean-ups and analysis of the radiation was limited due to the health risks posed to helicopter pilots.

Drones such as the Advanced Airborne Radiation Monitoring (AARM) system designed by Dr James MacFarlane at the University of Bristol could put an end to that. This particular craft is a hexacopter with a gamma spectrometer attached, which measures the amount of radiation being emitted from a chosen site. This can be done without a human anywhere near the area, so information can be received much more quickly and safely.

One of the most exciting commercial applications of drones is aerial photography and videoing. In the past, shooting any kind of media from the air required the hire of cranes or helicopters. Now, however, drone-mounted cameras can be bought for as little as £50 ($80), enabling amateur photographers and film-makers to capture amazing high-definition footage for a fraction of the cost.

Although drones might seem the futuristic domain of governments, the military and serious enthusiasts, there are a number of extremely practical day-to-day applications they can be used for. Amazon and DHL are both deep into the testing stage of delivery drones. You may remember the end of 2013 when Amazon claimed drones would be delivering small packages within five years. Currently the use of drones for commercial purposes is banned in the United States, but Amazon has petitioned the Federal Aviation Authority (FAA) to relax their rules to allow small drones to carry payloads of 2.3 kilograms (five pounds) to customers. This weight, they say, makes up 86 per cent of their deliveries and would take big, bulky and dangerous delivery vehicles off the road. DHL has already flown test missions from the German mainland to the island of Juist, off its northern coastline.

Commercial drones are a far cry from their headline-grabbing military cousins, but they are every bit as exciting, packed with fascinating technology and the ability to perform tasks that makes our lives, and the world, a little bit safer and a whole lot more fun.


The AARM won its inventor, Dr James MacFarlane, the 2014 ERA Foundation Entrepreneurs Award

© Thinkstock

LIFE-SAVERS

Discover the innovative drones designed to rescue those in need

The agility and efficiency of these incredible machines often means they are better equipped than humans or other vehicles for humanitarian tasks . From transporting aid to spotting someone in need, there is a variety of potentially life-saving drone aircraft projects that are currently in development.

One such initiative is the LifeLine Response app, a personal panic button that will summon a drone if you are in distress. If you are concerned about your safety, you can simply load the app and keep your thumb pressed on the screen or set a timer. If you get into trouble, you can release your thumb or fail to deactivate the timer, and the police will be called and a drone deployed to your location using GPS.

The idea is that the drone, which can travel at 97 kilometres (60 miles) per hour, will be able to scare off an attacker by sounding an alarm, follow them if they flee the scene, and collect information from the area before the police arrive. It is hoped the system could be used in cities across the world, with dozens of drones stationed at each law-enforcement headquarters waiting to spring into action.

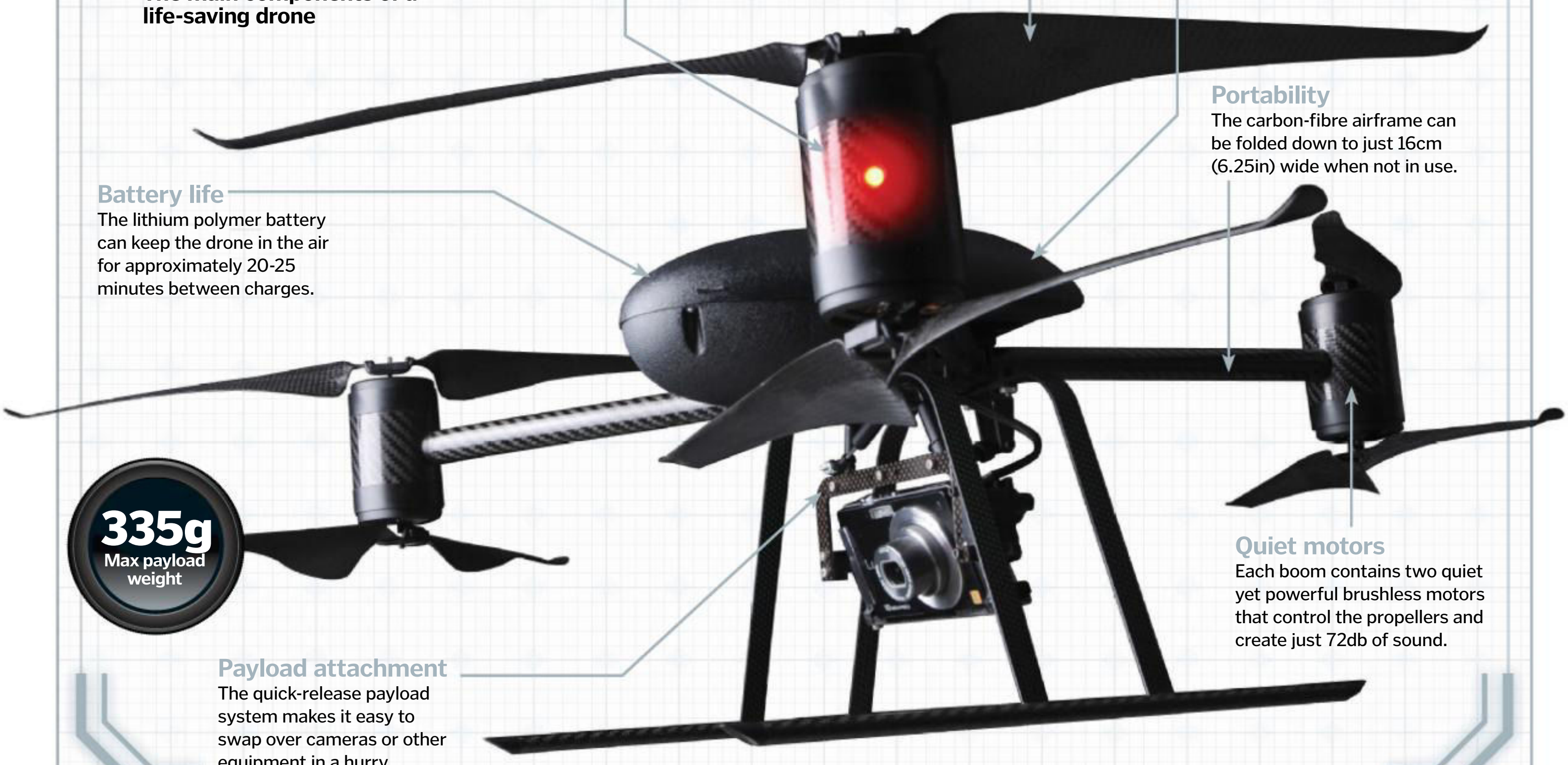
Another concept, developed by Dutch engineering student Alec Momont, involves 'ambulance drones' quickly delivering defibrillators to heart-attack victims. The drone would be able to transport the equipment within minutes, and then the operator can use two-way video supported communication to instruct a nearby helper to use it.

While some life-saving drones are still a work in progress, others are already being put to work. For example, Draganflyer drones are being used to provide a unique high-resolution view of disaster zones and crash sites to help teams on the ground locate victims, organise rescue missions and document the scene.

Draganflyer makes several different models of drone suited to both hobbyist and professional applications. These come with a choice of camera, including a GoPro and thermal-imaging camera, and are flown using a handheld controller, but you will need some training in order to operate one.

Draganflyer X6

The main components of a life-saving drone



LED lights
High-intensity LED lights aid navigation in the dark and can be remotely controlled by the operator.

Efficient propellers
The carbon fibre propellers help the drone climb to a maximum altitude of 2,438m (8,000ft) at 2m/s (6.5ft/s).

Sensors
11 different on-board sensors constantly monitor the altitude of the aircraft and send data to the controller.

Portability
The carbon-fibre airframe can be folded down to just 16cm (6.25in) wide when not in use.

Battery life
The lithium polymer battery can keep the drone in the air for approximately 20-25 minutes between charges.

335g
Max payload weight

Quiet motors
Each boom contains two quiet yet powerful brushless motors that control the propellers and create just 72db of sound.

Payload attachment
The quick-release payload system makes it easy to swap over cameras or other equipment in a hurry.

DID YOU KNOW? *85 per cent of roads in sub-Saharan Africa are inaccessible in the wet season, making drone delivery useful there*

Draganflyer story

We spoke to Kevin Lauscher from Draganflyer about the incredible innovations of the X6

What is the main purpose of the X6?
The Draganflyer X6 was developed as a safe and easy-to-use platform to carry an aerial imaging system that provided clear high-resolution images. At the time of development, systems that could carry a high-resolution camera were generally large, dangerous and difficult to control.

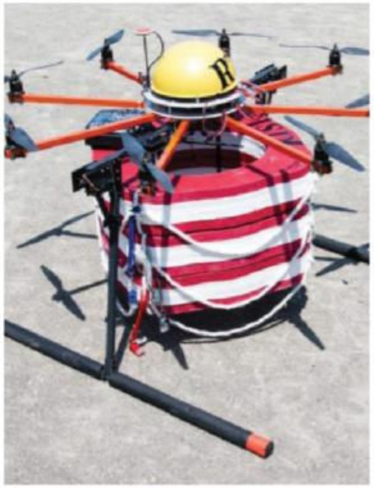
What sets it apart from other drones in existence?
It has a unique design with six rotors in the Y-style configuration, as well as its ability to fly even if it is missing one of the rotors. When it was first released, the concept of using sUAS (Small Unmanned Aircraft Systems) for civilian purposes was practically unheard of, so the attention it received made it stand out from other models.

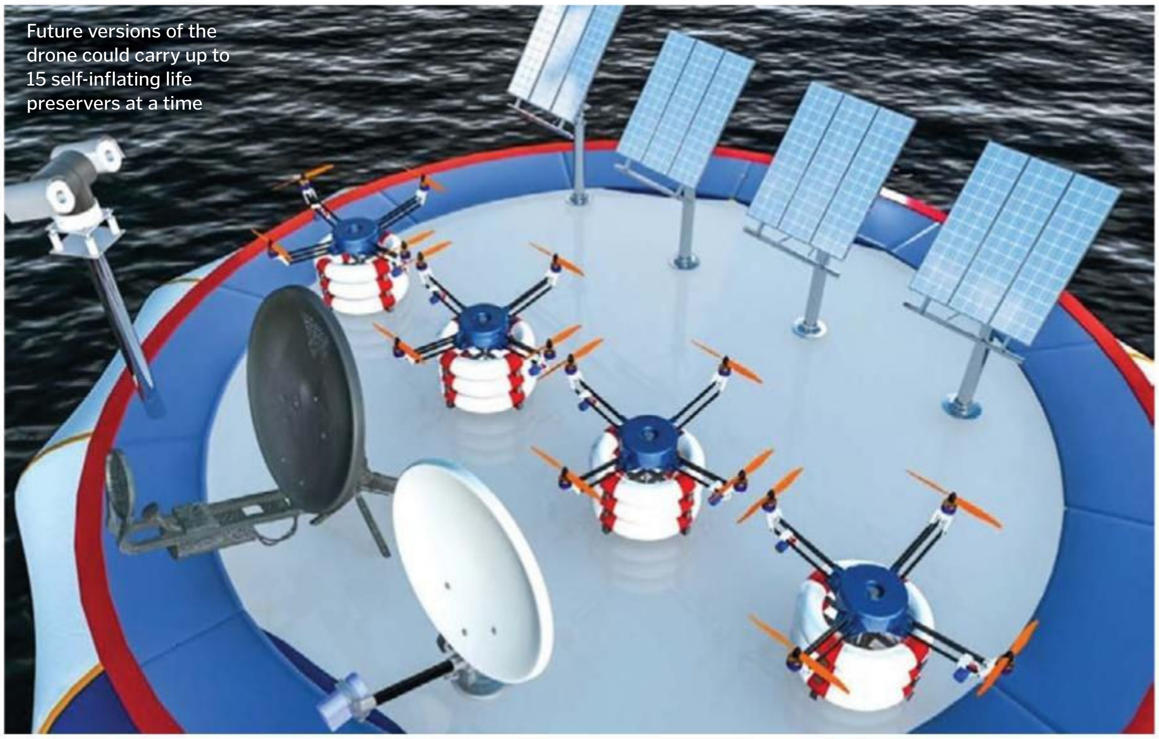
What are your hopes for the X6 in the future?
The Draganflyer X6 was our first industrial system and was responsible for setting a lot of firsts for the industry. Since then we have developed other improved systems based on our experience with the X6. Our hopes are to work some technology upgrades into its design and for it to again become a front-runner in the sUAS world.

The Draganflyer X6 can carry cameras weighing 335g (11.8oz) or less, including a GoPro

LIFEGUARD DRONE

Getting help to those in trouble out at sea is especially difficult and slow, particularly in adverse weather conditions. Iranian company RTS Lab hopes drones can solve this, as it is currently developing a new lifeguard robot called Pars. After hearing about the huge number of people that drown in the Caspian Sea each year, RTS Lab decided to create a multirotor drone that could help save human lives. As well as being able to fly above the water and be guided by GPS, Pars can also carry and drop life preservers to where they are needed. Although it is not able to pull people to safety, it can provide initial aid before the lifeguard arrives and monitor the situation by recording photos and video. A prototype has already been tested, and was able to reach a target 75 metres (246 feet) out to sea in just 22 seconds, while a human lifeguard took over a minute.

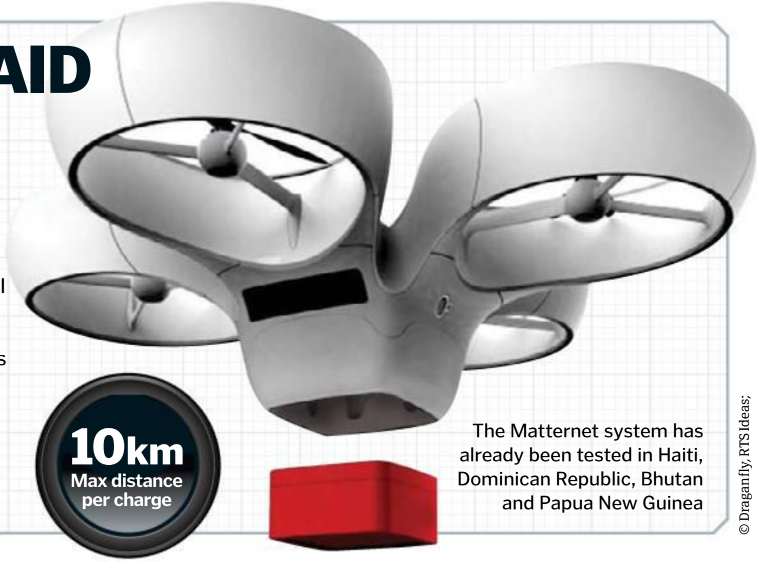




Future versions of the drone could carry up to 15 self-inflating life preservers at a time

DELIVERING AID

In many developing countries, rural roads become inaccessible during the rainy season, making it very difficult to transport much-needed medicine to those in need. Matternet – a network for transporting matter – aims to provide the solution. The plan involves autonomous drones, carrying up to two kilograms (4.4 pounds) of medical supplies, flying between several ground stations. These stations would allow the drones to collect or drop off their payload as well as swap batteries so they can keep flying for longer. The drones will use GPS and other sensors to navigate and an operating system would make sure they avoid adverse weather conditions and do not collide with each other.



10km
Max distance per charge

The Matternet system has already been tested in Haiti, Dominican Republic, Bhutan and Papua New Guinea

© Draganfly, RTS Ideas;

The Parrot AR.Drone 2.0 is controlled via an app on your Android or Apple device

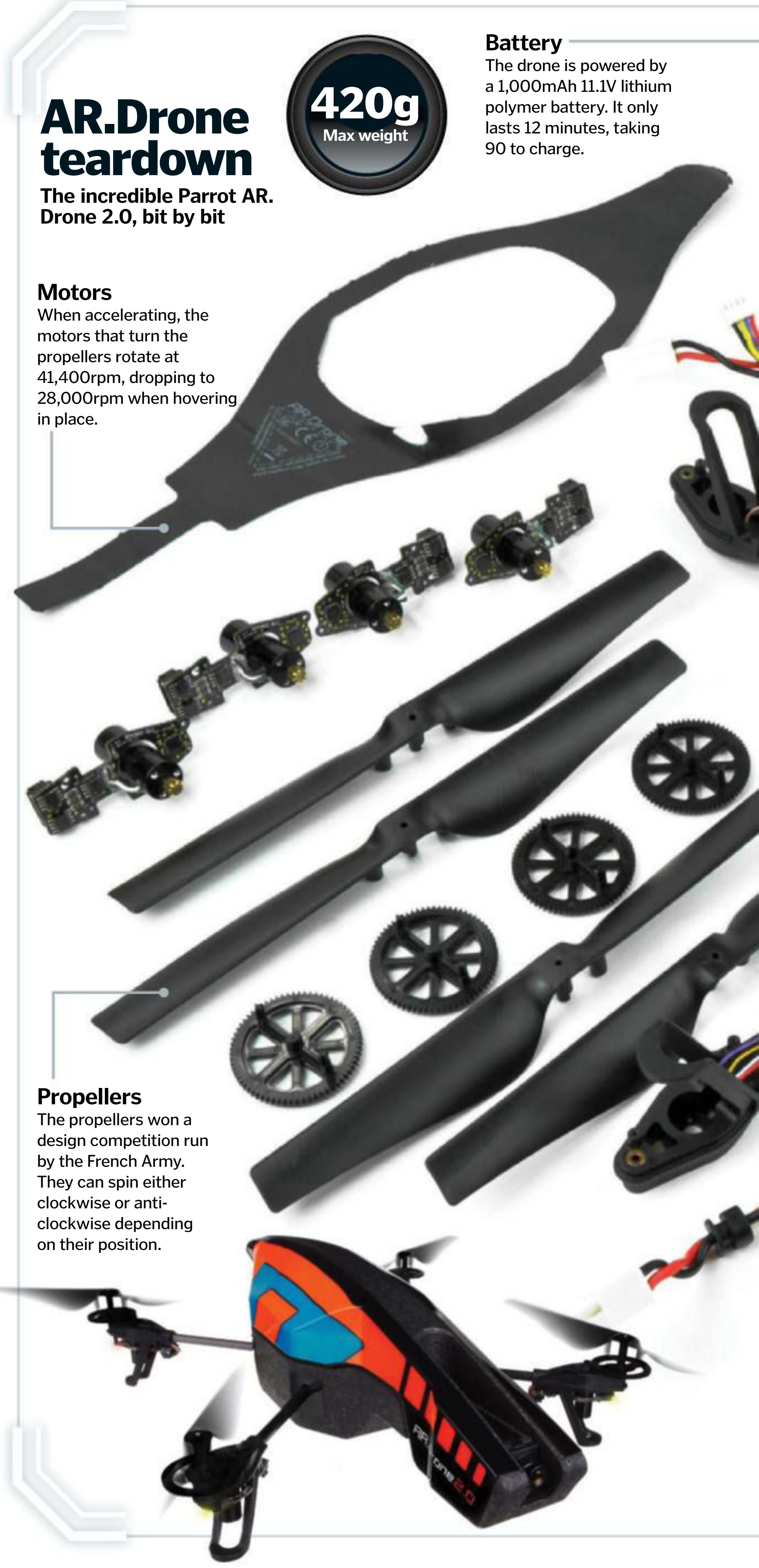
COMMERCIAL USE

The drones offering film-makers a whole new perspective

Drones such as the Parrot AR and the DJI Phantom 2 Vision+ have added a thrilling new dimension to personal photography and filmmaking. These clever gadgets are becoming more and more affordable for amateurs looking to capture Hollywood-style footage from unique angles. A Parrot AR. Drone, for example, will only set you back around £320 ($300) and has a built-in camera that can shoot 720-pixel high-definition video. It generates its own Wi-Fi hotspot so you can control it from up to 50 metres (165 feet) away via an app on your smartphone or tablet. The app also shows a live stream of the video being captured and lets you change its direction by simple tilting your device. It can even perform impressive flips in mid-air, and you can program automatic movements to compose your film like a professional director. If you do happen to crash the drone while filming a daring action sequence, then you can have a go at repairing it yourself as all of the parts and instructions are available online. Due to the relatively recent advancement of commercial drone technology, many countries are still developing laws regarding their use in public spaces. In the United States, the Federal Aviation Administration currently limits drones to be flown below 122 metres (400 feet), away from airports and air traffic, and within sight of the operator.

Using drones in a professional capacity requires a certificate of approval from the FAA, but it has recently granted six movie and television production companies permission to use drones on their sets. Some big blockbusters, such as *Skyfall* and the *Harry Potter* movies, have already been shot using unmanned drones for aerial footage, but filming took place in countries where this was allowed.

We are already seeing more and more drone-shot sequences on the big screen. Not only is this great news for us cinemagoers, as we will be treated to more creative camera angles, but it will also save the production companies a lot of money on helicopter and crane bills as they try to get above the action while filming.



AR.Drone teardown

The incredible Parrot AR. Drone 2.0, bit by bit

420g
Max weight

Battery
The drone is powered by a 1,000mAh 11.1V lithium polymer battery. It only lasts 12 minutes, taking 90 to charge.

Motors
When accelerating, the motors that turn the propellers rotate at 41,400rpm, dropping to 28,000rpm when hovering in place.

Propellers
The propellers won a design competition run by the French Army. They can spin either clockwise or anti-clockwise depending on their position.

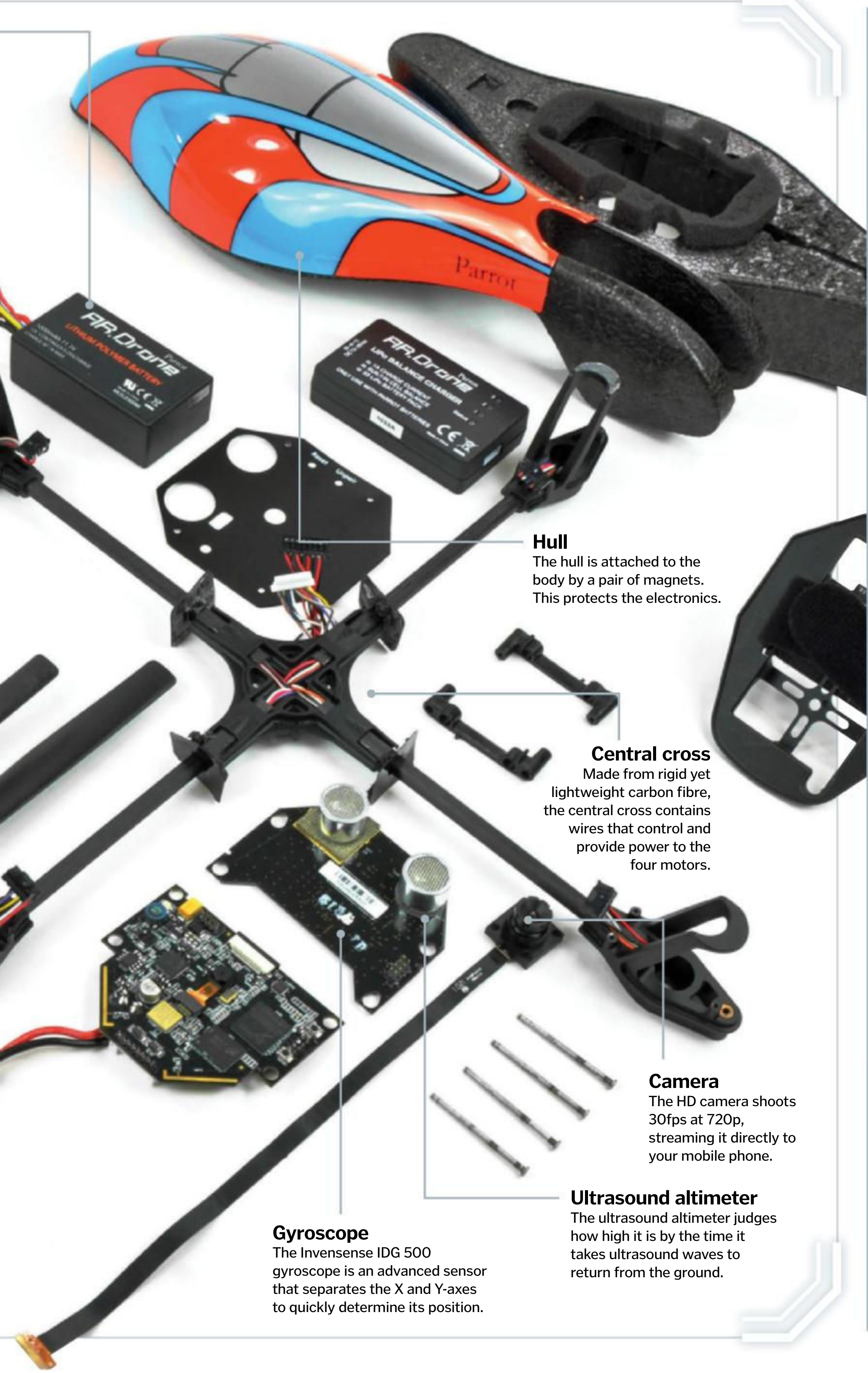
RECORD BREAKERS
DRONING ON

14 DAYS

LONGEST DRONE FLIGHT

The solar-powered Zephyr drone developed by UK firm QinetiQ flew for 14 days and 22 minutes in 2010, breaking the world record for the longest drone flight.

DID YOU KNOW? *TV coverage of skiers and snowboarders at the 2014 Winter Olympics in Sochi was shot by unmanned drones*



Hull
The hull is attached to the body by a pair of magnets. This protects the electronics.

Central cross
Made from rigid yet lightweight carbon fibre, the central cross contains wires that control and provide power to the four motors.

Camera
The HD camera shoots 30fps at 720p, streaming it directly to your mobile phone.

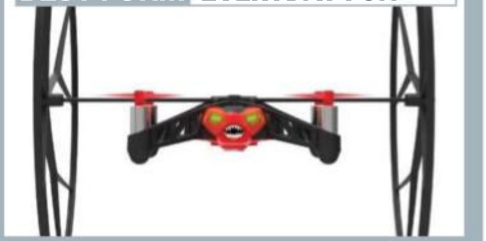
Ultrasound altimeter
The ultrasound altimeter judges how high it is by the time it takes ultrasound waves to return from the ground.

Gyroscope
The Invensense IDG 500 gyroscope is an advanced sensor that separates the X and Y-axes to quickly determine its position.

BEST FOR... **VIDEO STREAMING**

DJI Phantom 2 Vision+
Price: £940/$1299 • **Get it from:** www.dji.com

BEST FOR... **EVERYDAY FUN**



Parrot MiniDrone Rolling Spider
Price: £90/$100 • **Get it from:** amazon.co.uk

BEST FOR... **BEGINNERS**

Walkera QR Ladybird V2
Price: £60/$89 • **Get it from:** walkera.com

BEST FOR... **STUNTS**

Blade 350 QX V2
Price: £340/$575 • **Get it from:** quadcopters.co.uk

BEST FOR... **AFFORDABILITY**

Hubsan X4 H107
Price: £45/$70 • **Get it from:** amazon.co.uk

ANIMAL PROTECTORS

Drones are revolutionising the way wildlife conservationists keep poachers at bay

As well as helping to save the lives of humans, drones can also come to the rescue of animals in the wild. The Ol Pejeta Conservancy in Kenya is East Africa's largest black rhino sanctuary but has lost several rhinos to poachers in recent years. They have now teamed up with drone company Airware to see if unmanned aircraft can help protect this endangered species. A prototype Aerial Ranger drone, featuring a camera that can deliver real-time video and thermal imaging to a team on the ground, has been tested during the day and night to respond to poaching incidents. Ol Pejeta only has around 150 rangers, each having to cover 2.4 square kilometres (0.93 square miles) of the 364-square-kilometre (140.5-square-mile) sanctuary. This makes response times to poaching incidents very slow, but using a drone allows them to get there immediately and record footage of the offending individuals to use as evidence in court and deter further attacks. The drones would also be useful for monitoring the rhino, as well as protecting them. It would allow Ol Pejeta to conduct their annual wildlife census more regularly and cheaply, helping them to reliably keep track of the ecosystem.

Microsoft has also ventured into animal-tracking drones with their ZooTracer project. It involves attaching tiny GPS tracking and sensing devices, weighing just seven grams (0.25 ounces), to animals. These devices can record all sorts of data, such as the animal's speed, and then a drone is deployed to the animal's location to get the data back and monitor the animal further.

Ol Pejeta is home to three of the six remaining northern white rhino in the world

THE STATS
TRIMBLE UX5

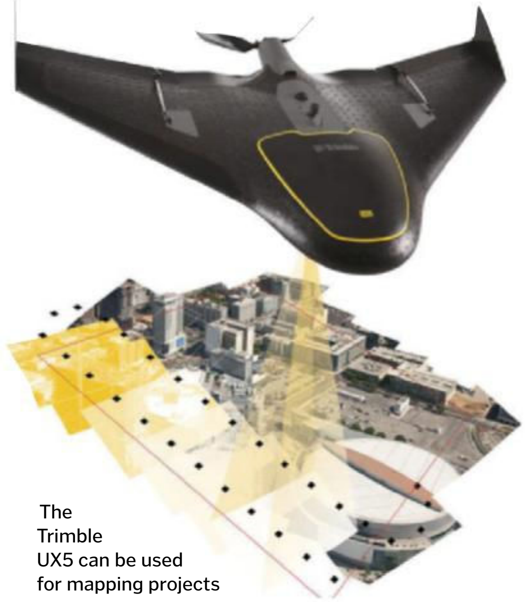
FLIGHT TIME **50min**
MAX ALTITUDE **750m**
SPEED **80km/h**
WINGSPAN **100cm**
WEIGHT **2.5kg**

DID YOU KNOW? *California's Casa Madrona Hotel uses drones to deliver champagne to guests in their $10,000-a-night luxury suite*

5 min
Set-up time
Trimble
UX5

AERIAL MAPPING

The drones making difficult jobs so much easier



The Trimble UX5 can be used for mapping projects

The advancements in drone technology have been extremely beneficial for industry. From engineering and surveying to mining and agriculture, a variety of markets are embracing this new tool to improve day-to-day operations. The Trimble UX5 is one of the leading surveying and mapping drones being used by many companies. It features a 16.1-megapixel camera for taking several overlapping high-resolution images, which are then layered together by specialist image-editing software to collate a map. By taking several photos from different locations, triangulation can be used to determine accurate coordinates and create three-dimensional plans of the area free from distortion. This proves invaluable when planning new infrastructure, inspecting mines and monitoring forests, and because the drone is autonomous and unmanned, it provides a much safer, quicker and cheaper solution than the pilot-controlled alternative. Plus, it is made from expanded polypropylene, a durable material that enables it to fly in practically any weather and even float on water.

The Trimble UX5 takes off from an angled launcher that helps it safely clear the ground and climb into the air, where it then flies a preplanned route travelling back and forth over the area. An application on the Trimble Tablet Rugged PC is used to plan flights and operate the drone easily and reliably, but once in the air it uses GPS to navigate. When its flight is over, the drone automatically begins its landing sequence, circling above a preplanned landing spot and using reverse thrust to help it land in tight spaces.

DELIVERY DRONES

Although commercial drones are mainly being used by specialist industries, consumer companies certainly haven't failed to notice their potential. In the not-so-distant future, the skies above us could be swamped with a network of drones delivering our shopping, or even fast food, straight to our front door. Many big companies are testing this new delivery method, but it is likely to be several years before the idea becomes reality. Many countries, including the United States, do not allow drones to be flown at low altitude over residential areas, and the autonomous aircraft currently have no way of avoiding obstacles en route.

amazon PrimeAir

Amazon Prime Air

Amazon is already developing and testing drones for delivering packages weighing up to 2.3 kilograms (five pounds) to customers within 30 minutes of ordering. The retail giant is just waiting for permission from the FAA before it can roll out the new system, which is expected to happen in 2015.

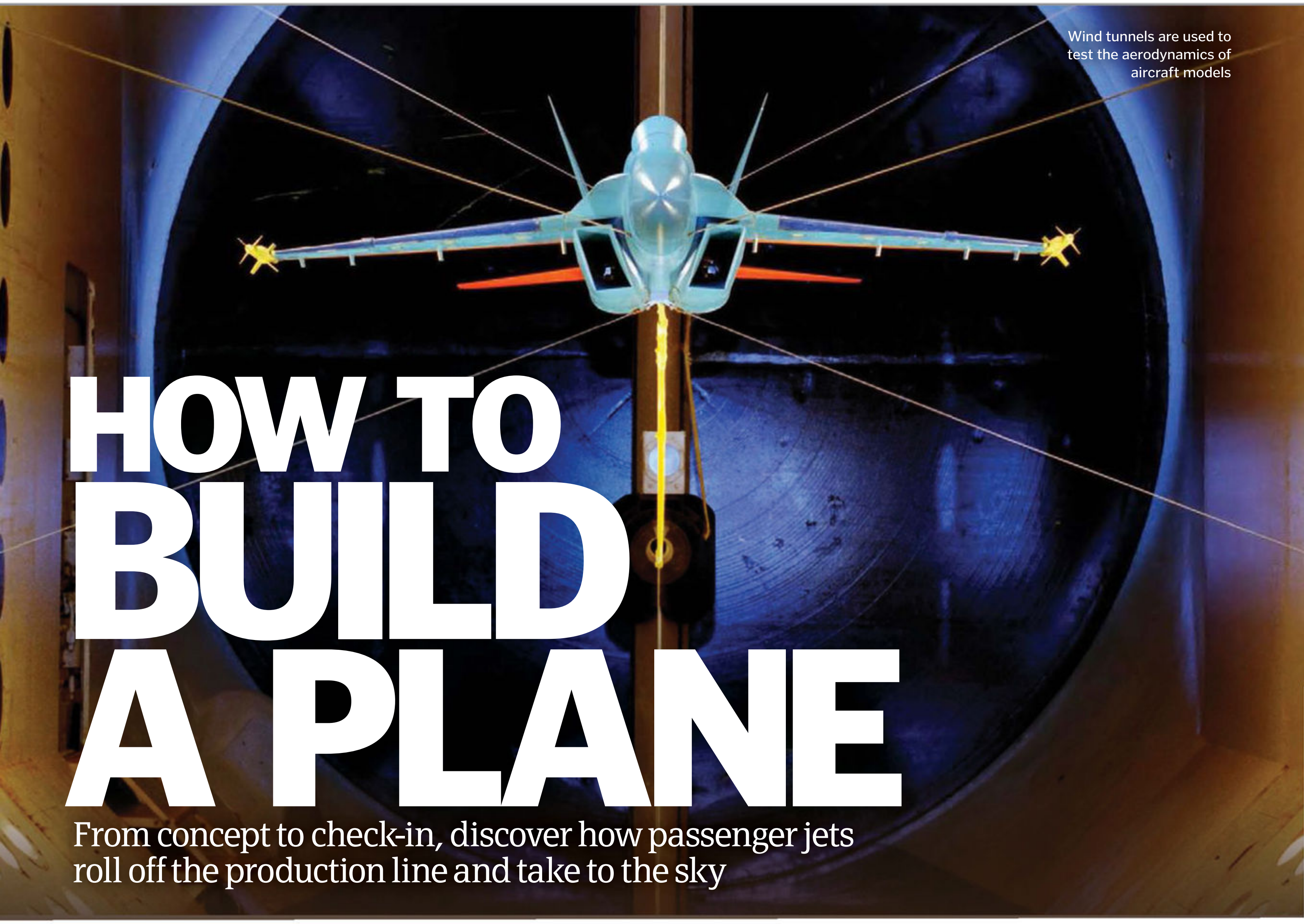
DHL parcelcopter

Logistics firm DHL is the first company to launch a drone-based delivery service. Its 'parcelcopter' is currently being used to deliver small parcels to the German island of Juist in the North Sea. A restricted flight area has been established for the service, which mainly delivers medication and other urgently needed goods.

Burrito Bomber

The Burrito Bomber is a Mexican food-delivery system that lets you place your order via an app. A drone will then fly to your location and parachute your snack down to you in a custom-made Burrito Delivery Tube. It should be up and running – in the US, at least – once the FAA updates its regulations.

© DHL; Amazon; Trimble; Draganfly; RTS Ideas;



Wind tunnels are used to test the aerodynamics of aircraft models

HOW TO BUILD A PLANE

From concept to check-in, discover how passenger jets roll off the production line and take to the sky

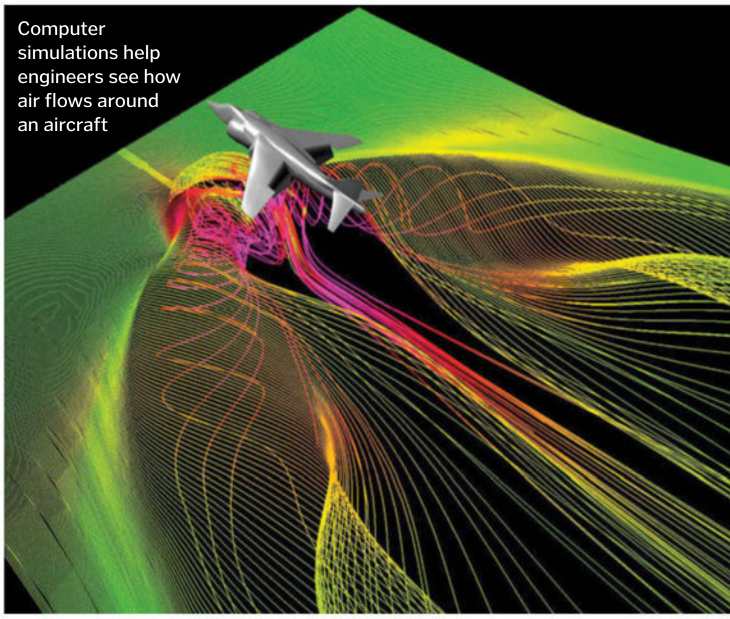
STEP 1:
Design and testing

Before building can begin, the aircraft must first be designed in great detail. Thousands of engineers across the world often work together to design one plane, and it can take several years to get it right.

When designing an aircraft, there are four main areas to consider. First it must be aerodynamic, so that air flows around it with as little resistance as possible. To test this, engineers create computer simulations of the plane and examine how airflow and pressure will affect the body and wings when it is in flight. They then build a scale model of the aircraft and place it in a wind tunnel, where air is blown towards it at varying speeds in order to test its flight performance.

Next they must design the engines, making sure they are powerful enough to keep the aircraft in the air, fuel efficient to minimise running costs and pollution, and not too noisy. The way the plane handles in the air must also be considered, and so flight simulators are used to ensure it is easy and safe for the pilot to fly.

Finally, engineers determine what material to build the aircraft from, considering strength, weight, durability and cost, and how exactly it will be built.



Computer simulations help engineers see how air flows around an aircraft

DID YOU KNOW? *By 2018, Airbus aims to be building ten A350 aircraft every month, completing one every two working days*

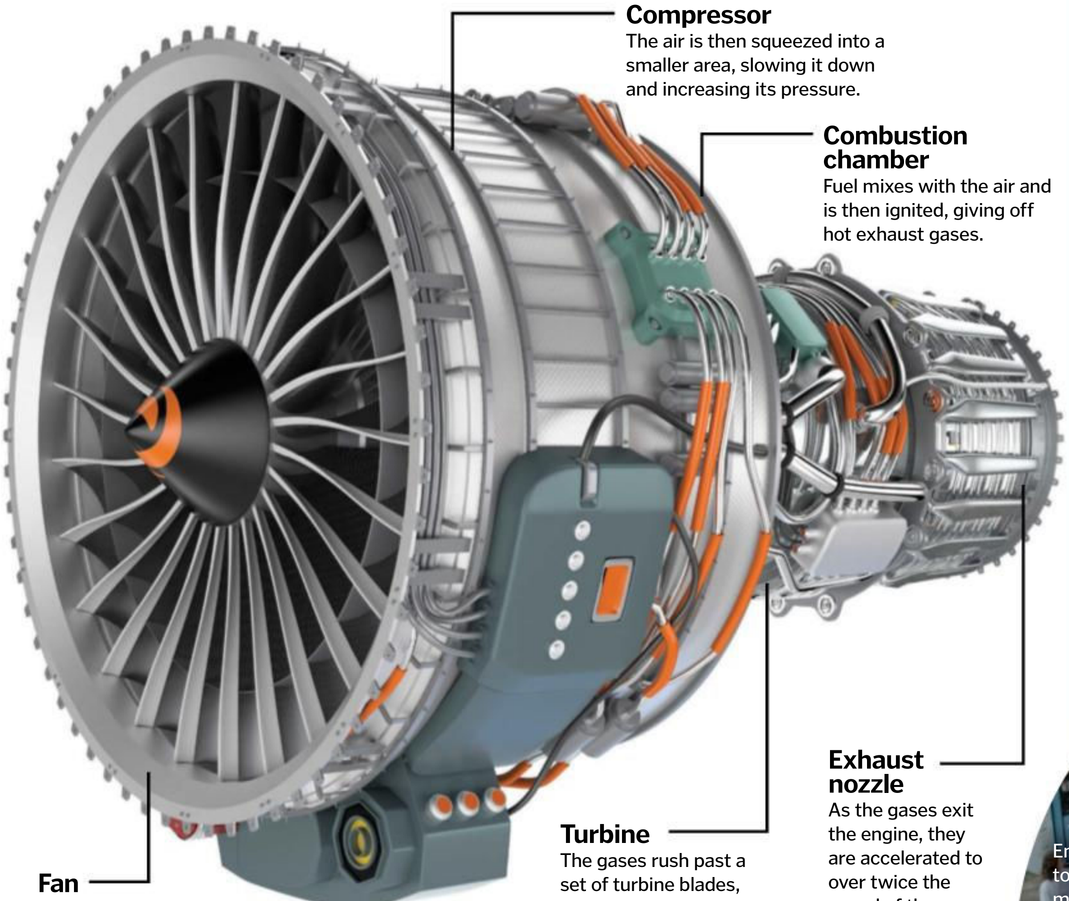
STEP 2:
Making the parts

A plane is made up of millions of different parts, from the enormous fuselage shell to the tiny rivets that hold it together. Many are made by the aircraft manufacturer itself, while others, including the engines and landing gear, are produced by external contractors. A huge number of different skills are required to build an aircraft, from mechanics and electronics, to plumbing and painting, so it takes teams from all over the world to make the finished product. Coordinating the production of a plane is a task in itself, as everything has to be made to a tight schedule and then transported to where it is needed for assembly. Plus, each part has to undergo rigorous testing to ensure it functions properly and is safe to use in the final aircraft.

Engineers building the aircraft spars, supporting beams that run the length of the wings

2.65 million
The number of parts in an Airbus A350 jet

How do jet engines work?
The machines that turn fuel into thrust



Compressor
The air is then squeezed into a smaller area, slowing it down and increasing its pressure.

Combustion chamber
Fuel mixes with the air and is then ignited, giving off hot exhaust gases.

Exhaust nozzle
As the gases exit the engine, they are accelerated to over twice the speed of the incoming air to create thrust.

Turbine
The gases rush past a set of turbine blades, causing them to spin and drive the compressor and fan.

Fan
The big spinning fan at the front of the engine sucks in large volumes of air.

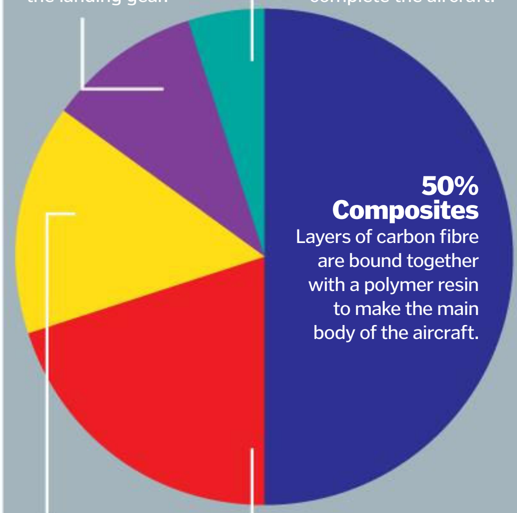
What is a plane made of?

The very first planes were built from wood and fabric, but thankfully modern aircraft are made of much stronger – and less flammable – stuff. Metal was once the material of choice, with strong, light aluminium used to build the main airframe and outer skin, but it was soon discovered to be corrosive and susceptible to stress.

Nowadays, manufacturers favour composite materials, which are stronger and more durable, yet still incredibly lightweight. To build the wings and fuselage of an aircraft, layers of carbon fibre and resin are built up, like layering several strips of sticky tape on top of each other.

The entire aircraft part is then placed in an enormous oven, called an autoclave, to harden the composite material until it becomes incredibly strong. Once it is complete, the windows and doors are cut out, and the whole thing is covered in a green protective coating, ready to be assembled.

What's in a plane?
The materials used to build a typical jumbo jet



10% Steel
Steel is stronger than aluminium so is used to build the landing gear.

5% Other
Plexiglass windows, fabric upholstery, and many other materials complete the aircraft.

50% Composites
Layers of carbon fibre are bound together with a polymer resin to make the main body of the aircraft.

15% Titanium
Its ability to withstand high temperatures makes titanium a good choice for constructing the engines.

20% Aluminium
Lightweight and strong, aluminium is still the main metal of choice for many parts of an aircraft.

Enormous ovens are used to harden the composite material on an aircraft

STEP 3:
The final assembly

Putting together an enormous passenger jet requires an even more enormous building to do it in. Aircraft hangars are some of the largest buildings in the world, and are able to house several aircraft at once as they are passed from team to team along the assembly line.

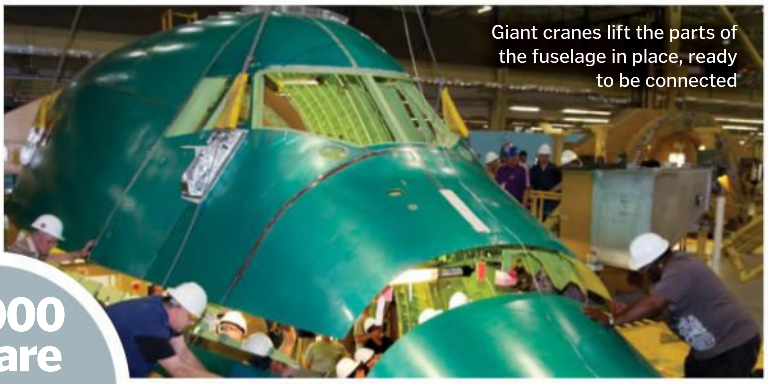
First though, all the parts need to get there, and this is done by road, river and even air. Cargo aircraft such as the Airbus Beluga and Boeing Dreamlifter, are designed specifically to transport large pieces of aircraft to the final assembly point.

The individual pieces of the fuselage are fastened together using thousands of rivets, then the electrical and hydraulic systems, plumbing and insulation are installed. Next the wings are connected, using laser alignment to ensure they are perfectly level, and the landing gear is fitted underneath. This is followed by the tail, vertical stabilisers and an auxiliary power unit, which provides power to the aircraft when the engines are turned off. The cabin and cockpit interiors are then added, complete with seats and toilets.

Last of all, the engines are installed, as these are the most expensive component of the aircraft, representing over a third of its total value. Once assembly is complete, the plane is painted – this can take up to a week, depending on its size.

Planes are assembled in huge aircraft hangars by thousands of engineers

Aircraft slowly move along the assembly line as new parts are added


Giant cranes lift the parts of the fuselage in place, ready to be connected

72,000 square metres
The size of the Airbus aircraft hangar in Toulouse, France

The engines are fitted last, as they are the most expensive part of the aircraft

BELUGA XL
AIRBUS
The Airbus Beluga cargo plane is so-called because it resembles a beluga whale

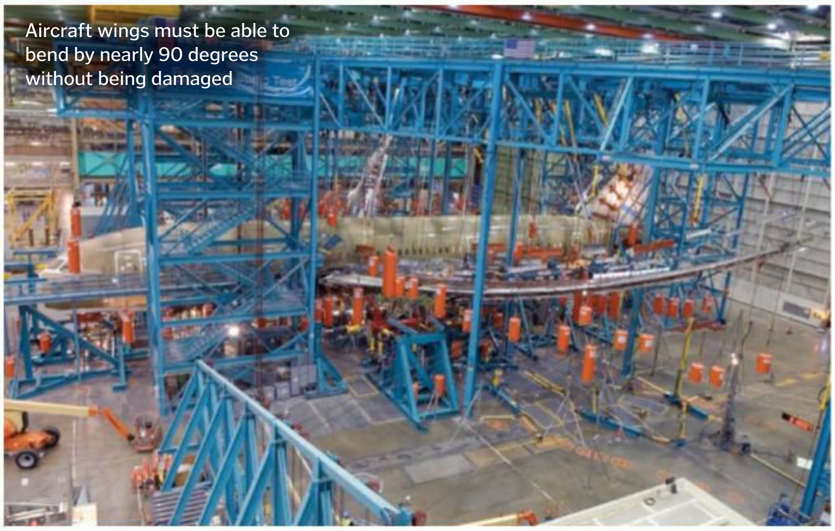
DID YOU KNOW? *Some aircraft hangars are so big that air circulation systems are installed to prevent clouds from forming inside*

STEP 4:
In-flight testing

If the aircraft is a new design, then the first few planes to roll off the assembly line undergo extensive prototype testing. This involves fitting them with a variety of sensors, and flying in extreme conditions, such as very hot and cold climates and really high altitudes. The individual elements of the aircraft are also tested, as the wings are forcibly bent to evaluate their strength, and dead birds are fired into the engines to see how they would cope with a bird strike.

To ensure the plane can withstand the stress of multiple take-offs and landings, computer-operated hydraulic jacks place heavy loads on the airframe for extended periods of time, and the plane may even be subjected to artificial lightning strikes to see how it performs in a storm. Once the first few planes have been rigorously tested, all successive aircraft are taken on their own test flights before they are deemed airworthy and delivered to airlines around the world.

Aircraft are tested on their ability to land on a waterlogged runway



Aircraft wings must be able to bend by nearly 90 degrees without being damaged

Ready for take-off!

CIT AEROSPACE
737-8

© Corbis; Alamy; Science Photo Library; Thinkstock

> "It can seat up to 19 people in upper class comfort"

The luxury of the Lineage 1000 jet

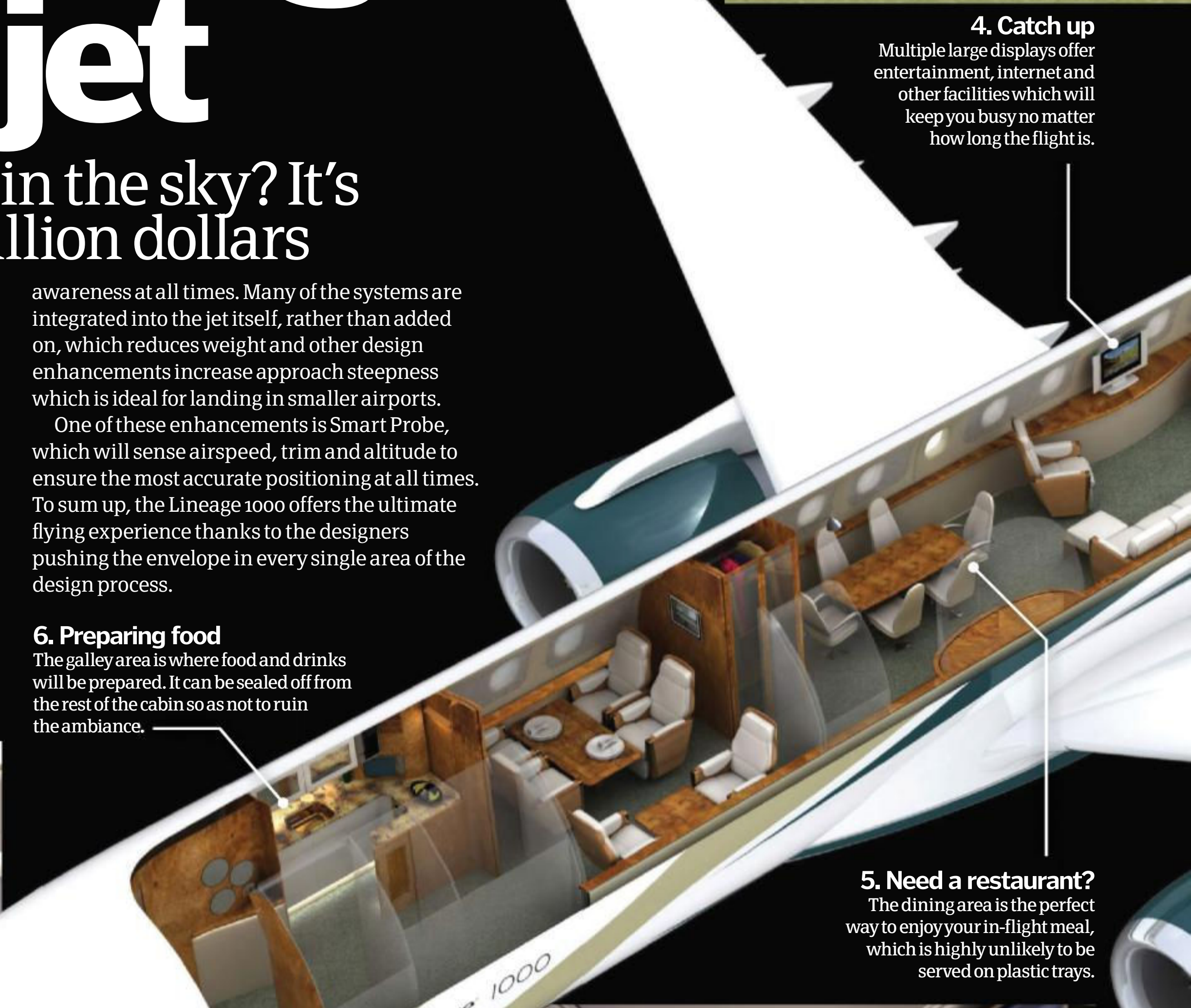
A luxurious hotel in the sky? It's yours for a few million dollars

The best private jets offer more than just rows of seating and the Lineage 1000 includes a shower room, a double bed, a lounge and an office, a bar and almost everything else you need in a space that is three times larger than traditional business jets. It can seat up to 19 people in upper class comfort and the interior has been built to include five privacy areas, Wi-Fi and real-time flight displays, all thanks to the larger space and innovative interior design. On top of this the turbofan engine technology and fuselage interior design ensure low noise for passengers.

Safety has not been ignored and the pilot has a CMC (central maintenance computer) at hand to predict potential problems and offer solutions, plus an enhanced vision system to improve awareness at all times. Many of the systems are integrated into the jet itself, rather than added on, which reduces weight and other design enhancements increase approach steepness which is ideal for landing in smaller airports.

One of these enhancements is Smart Probe, which will sense airspeed, trim and altitude to ensure the most accurate positioning at all times. To sum up, the Lineage 1000 offers the ultimate flying experience thanks to the designers pushing the envelope in every single area of the design process.

Filthy-rich airlines, you are clear for take off



4. Catch up
Multiple large displays offer entertainment, internet and other facilities which will keep you busy no matter how long the flight is.

6. Preparing food
The galley area is where food and drinks will be prepared. It can be sealed off from the rest of the cabin so as not to ruin the ambiance.

5. Need a restaurant?
The dining area is the perfect way to enjoy your in-flight meal, which is highly unlikely to be served on plastic trays.

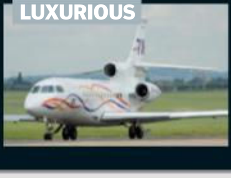
8. The serious stuff
Inside the cockpit are some seriously clever systems designed to aid safety and ensure the least disruption possible.

What the opposite to economy class looks like!

© Image courtesy of Embraer

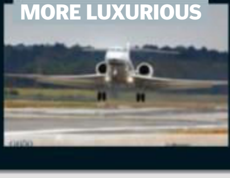
HEAD 2 HEAD
LUXURIOUS PRIVATE JETS

LUXURIOUS



1. Falcon 7X

MORE LUXURIOUS



2. Gulfstream G650

The Gulfstream is designed to offer flexible comfort and succeeds, and at 53 feet offers great scope for individual cabin design.

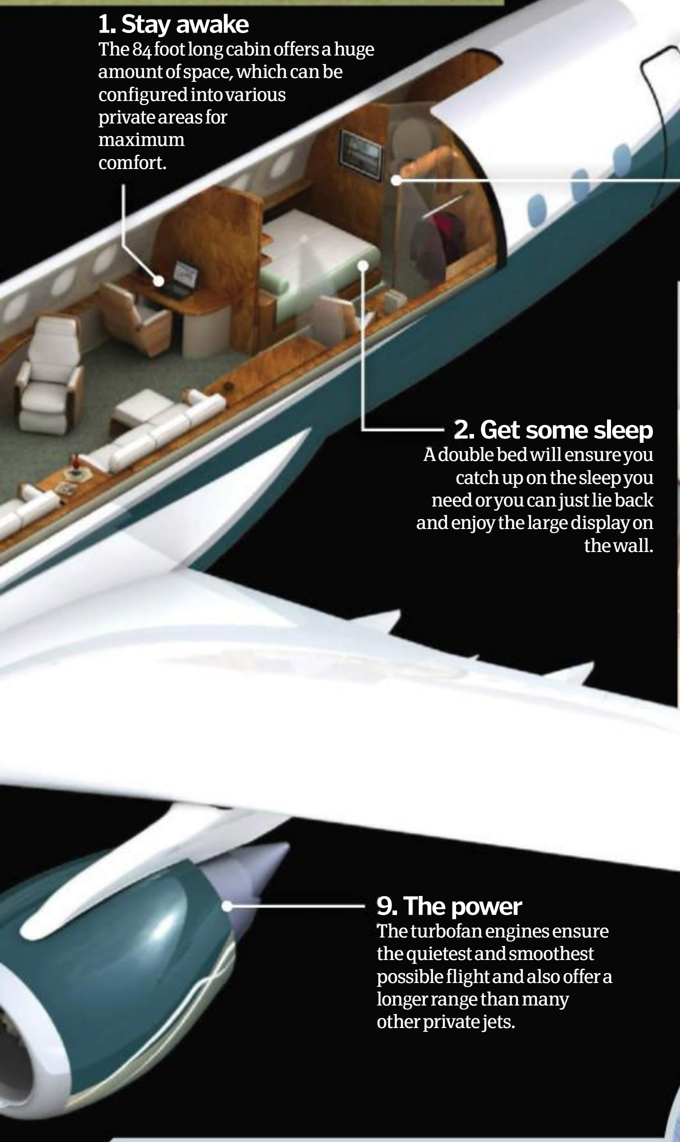
MOST LUXURIOUS

3. Embraer Lineage 1000

With a cabin length of 84 feet the Lineage 1000 is easily the most luxurious thanks to the most luxurious thanks to the comfort and individualism offered in every corner.

DID YOU KNOW? *The Lineage 1000 interior can be configured from 25 different cabin modules*

Pure airborne luxury



1. Stay awake
The 84 foot long cabin offers a huge amount of space, which can be configured into various private areas for maximum comfort.

7. More than a wardrobe
The 351 cubic feet walk-in baggage compartment lets you take your entire wardrobe with you and there's still room for your other luxuries.

3. Freshen up
A fully equipped luxurious bathroom will help you arrive at your destination fresh as a daisy and the fittings rival the best hotels.

2. Get some sleep
A double bed will ensure you catch up on the sleep you need or you can just lie back and enjoy the large display on the wall.

No better place to join the mile high club

9. The power
The turbofan engines ensure the quietest and smoothest possible flight and also offer a longer range than many other private jets.

© Gulfstream Aerospace Corp

Know your engines
Jet engines are almost universally used to power private jets and passenger aircraft, but there are some significant differences between the type used on each. Private jets often use high-bypass turbofans, which are very quiet and offer enhanced fuel efficiency plus excellent thrust to ensure better performance. These engines are usually placed below the wing to reduce drag and turbulence, particularly during take off, which is crucial for a small passenger plane. Tests have proved that turbofan engines are highly reliable and that most pilots should never suffer an engine incident in their entire career. The Gulfstream G550 is one example which is powered by twin Rolls-Royce turbofans.

The statistics…
Lineage 1000
Manufacturer: Embraer
Class: Heavy jet
First flight: 26 October 2007
Wingspan: 28.72m
Length: 36.24m
Height (outside): 10.28m
Cabin height: 2m
Cabin volume: 115.7m^3
Cabin area: 68.85m
Weight max payload: 55,000kg
Max speed/cruise speed: 480 knots/469 knots
Propulsion: GE CF34-10E turbofans (x2)
Ceiling: 12,497km

Know your jets

Class: VLJ
Passengers: 4-8
The VLJ (very light jet) is often used as an air taxi to travel between local airports in a country.

Class: Light jets
Passengers: 5-9
Light jets are similar to VLJs in their target market, but are faster and offer some extra luxuries for quick journeys.

Class: Mid-size jets
Passengers: Up to 18
Mid-size jets typically carry 8-12 people, but some can accommodate 18 people for short flights.

Class: Super mid-size jets
Passengers: Up to 19
These jets are designed to offer luxury for transatlantic flights and give more cabin space and luxuries.

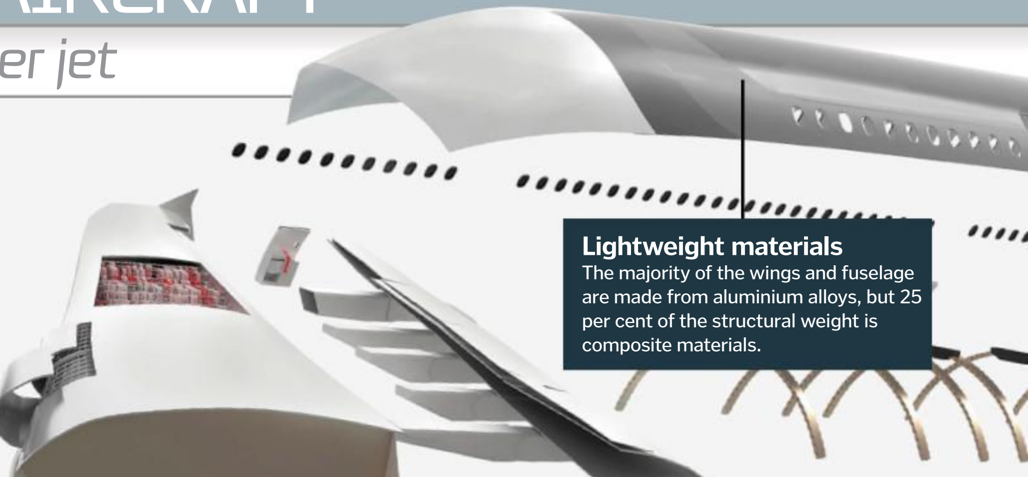
Class: Large size jets
Passengers: Up to 19
Large size jets are designed for longer distances and New York to Tokyo is quite possible with high levels of comfort.

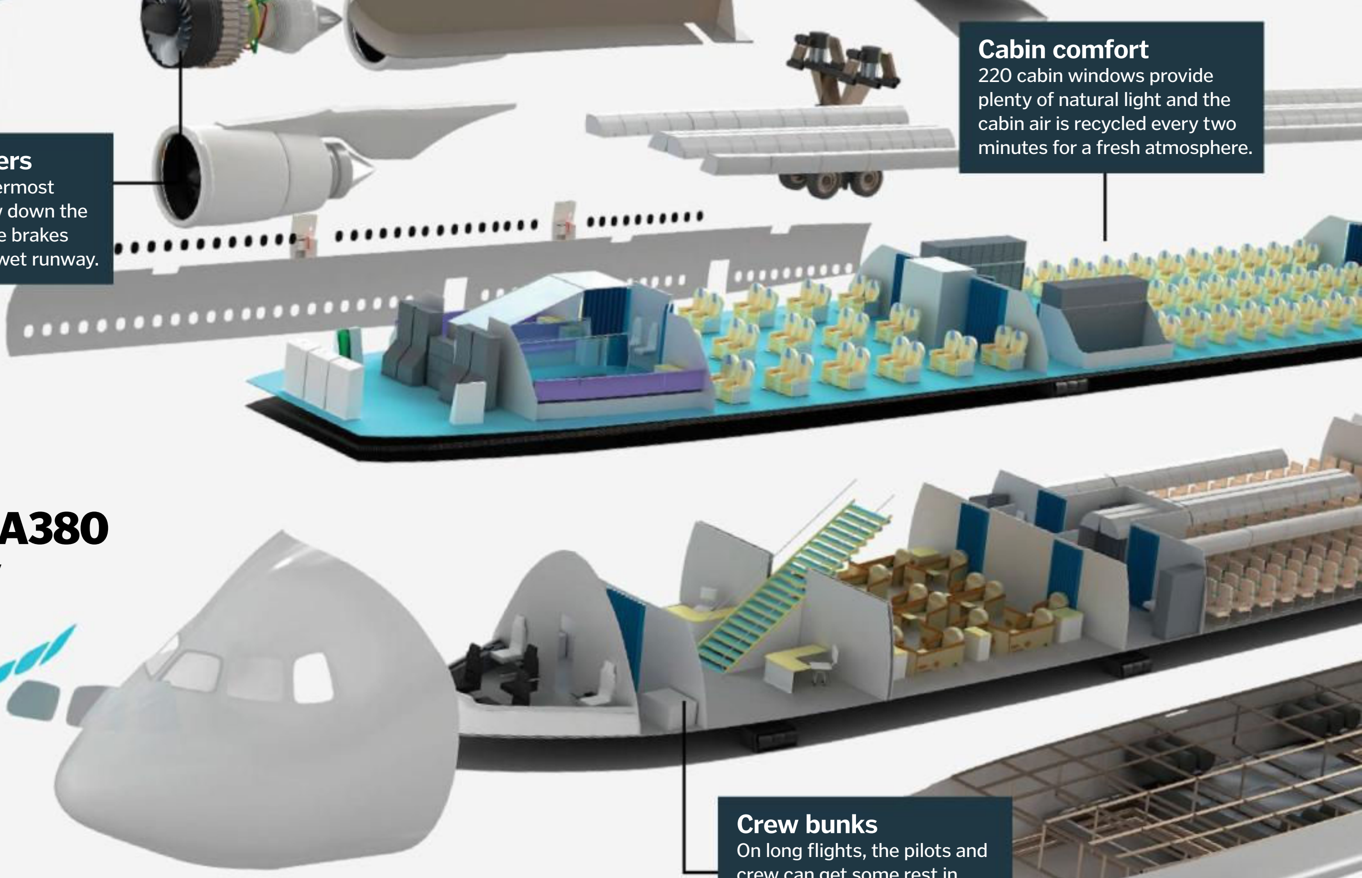
Class: Heavy jets
Passengers: 100s
Heavy jets range in size and can be privately hired. The Lineage 1000 is in this class, but is small compared to some.

The Airbus A380 is greener and quieter than many other passenger jets

Boarding the A380

The incredible technology inside this sky giant





Lightweight materials
The majority of the wings and fuselage are made from aluminium alloys, but 25 per cent of the structural weight is composite materials.

Cabin comfort
220 cabin windows provide plenty of natural light and the cabin air is recycled every two minutes for a fresh atmosphere.

Thrust reversers
Located on the innermost engines, these slow down the aircraft to assist the brakes when landing on a wet runway.

Crew bunks
On long flights, the pilots and crew can get some rest in bunks located below the lower deck or behind the cockpit.

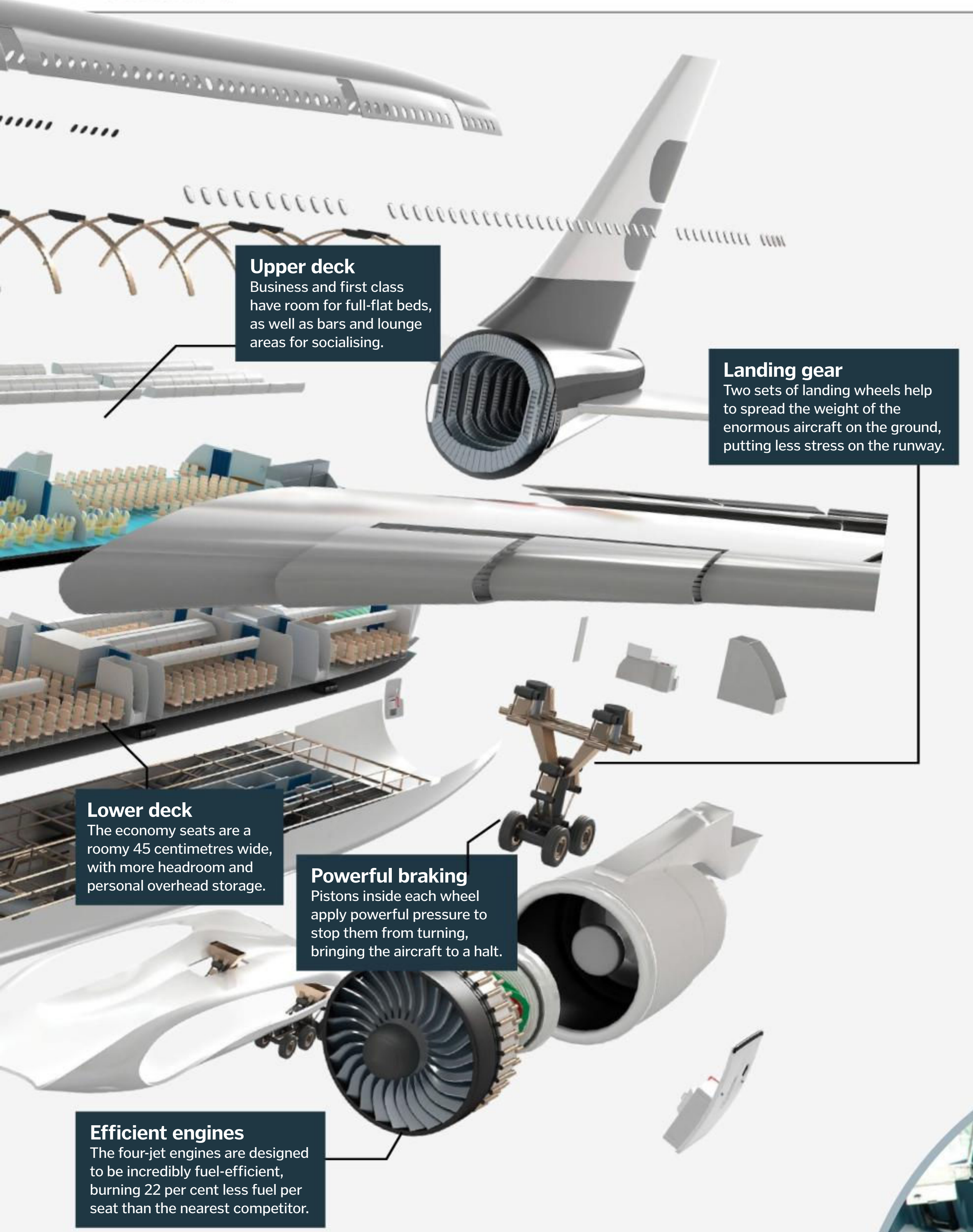
The world's largest passenger jet

How does the enormous double-decker Airbus A380 get off the ground?

Ferrying travellers all over the globe is an expensive business for the world's airlines, so it makes sense that they would want to pack as many passengers as possible onto each aircraft, reducing the number of flights they need to make. Thanks to its double-decker design, the Airbus A380 is capable of carrying up to 853 passengers at a time, if it is in a single-class cabin configuration. That's over 150 more than the aircraft's competitor, the Boeing 747-8. Most A380s, however, feature four separate classes, with economy and premium economy on the lower deck and the more spacious business and first class upstairs, which reduces the passenger number to 544. This is still a 40 per cent increase on the 747-8's four-class capacity.

As well as being the largest passenger jet, the A380 is one of the quietest, with dampeners reducing engine noise to half that of other jets. It is also more environmentally friendly, because it needs to take fewer flights to deliver the same amount of passengers, and the fuel-efficient engines are claimed to give off 22 per cent fewer CO_2 emissions than the jet's closest competitor.

DID YOU KNOW? *The Airbus A380 is covered in three layers of paint weighing around 500 kilograms*



Upper deck
Business and first class have room for full-flat beds, as well as bars and lounge areas for socialising.

Landing gear
Two sets of landing wheels help to spread the weight of the enormous aircraft on the ground, putting less stress on the runway.

Lower deck
The economy seats are a roomy 45 centimetres wide, with more headroom and personal overhead storage.

Powerful braking
Pistons inside each wheel apply powerful pressure to stop them from turning, bringing the aircraft to a halt.

Efficient engines
The four-jet engines are designed to be incredibly fuel-efficient, burning 22 per cent less fuel per seat than the nearest competitor.

Building an aircraft of this enormous size does present a few problems, though. Many airlines have had to modify their aircraft hangers to accommodate the increased height and wingspan of the A380, and some airports just don't have enough space for them to park. Also, to speed up the process of boarding and offloading such a large number of passengers, two gangways from the aircraft to the terminal building are needed – a set-up that only certain airports are capable of.

As a result, the A380 can usually be found travelling to and from the world's biggest international airports, making the most of its 15,200-kilometre range to deliver passengers to far-flung destinations in style.

Two staircases provide access to the aircraft's upper and lower decks

Next-gen flight deck

The cockpit of the A380 is designed to be very similar to that of other Airbus aircraft, minimising the amount of time that pilots have to spend training to fly it. It features an instrument panel with eight large, interactive liquid crystal display units showing navigation, engine and systems information, as well as a transparent head-up display that superimposes information over the pilot's view. An electronic library also replaces the traditional paper documentation used by pilots, allowing them to locate operational information more easily and analyse the aircraft's performance. As the plane prepares for landing, the process is made easier as the flight crew can pre-select the optimum runway exit at their destination airport, and leave the autopilot to regulate deceleration after touchdown accordingly. This helps to reduce runway occupancy time and therefore increase the number of aircraft the airport can handle at any given time.

The A380's cockpit is designed to make Airbus pilots feel at home

© Airbus; Getty

THE NEW CONCORDE

Concorde's successors are now on the horizon, offering Mach-shattering speeds, alongside hugely reduced noise and fuel consumption compared to their famous forebear

LOCKHEED MARTIN
NASA

Fuselage
The fuselage has been designed in line with the Sears-Haack body, a cigar shape that grants the lowest theoretical wave drag.

In 1976 we could fly commercially from London to New York in just three and a half hours. That's over 5,550 kilometres (3,460 miles) at an average speed of 27 kilometres (17 miles) per minute. For context, the same journey in a Mini Metro travelling continuously at 97 kilometres (60 miles) per hour would take close to 58 hours (almost two and a half days) – and that's not considering the fact a Mini can't fly!

Today, crossing the 'pond' – ie the Atlantic – takes more like seven and a half hours, a trip that definitely puts the 'long' into long-haul flight. So, this raises the question: what went wrong? A one-word answer is sufficient: Concorde. The Concorde supersonic jet, the piece of technology that allowed such outrageous flight times was retired for good in 2003 after 27 years of service (for more information see the 'End of Concorde' boxout). Further, no other supersonic jet has been introduced in its absence – leaving customers stuck travelling at subsonic speeds no matter where they wish to fly around the globe.

Things, however, are about to change. Driven by the ever-growing notion of the global village – the interconnectedness of all nations – and fired by the gaping void left by Concorde, a new wave of supersonic jetliners are in production, aiming to pick up where Concorde touched down and radically transform the speed, efficiency and impact of commercial supersonic travel.

From Lockheed Martin's Green Machine concept (a supersonic jet capable of mitigating the effects of sonic boom) through Aerion Corporation's Supersonic Business Jet (a machine that introduces a radical new technology called natural laminar flow) and on to Boeing's Icon-II design (an aircraft that boasts far greater noise reduction and fuel efficiency) the future of this industry is already looking very exciting. For the first time, private companies are collaborating with the best research institutes in the world (NASA, for one) to make supersonic flight a reality once more, outside of the military sphere.

Of course, while the roadmap to realisation is becoming more and more concrete with each

RECORD BREAKERS
POND-HOPPING

2HRS52MINS59SECS

FASTEST TRANSATLANTIC FLIGHT

On average Concorde took three and a half hours to get from London to New York, but on 7 February 1996, the supersonic aircraft completed the trip in under two hours and 53 minutes.

DID YOU KNOW? Lockheed Martin will work closely with NASA to create the Supersonic Green Machine

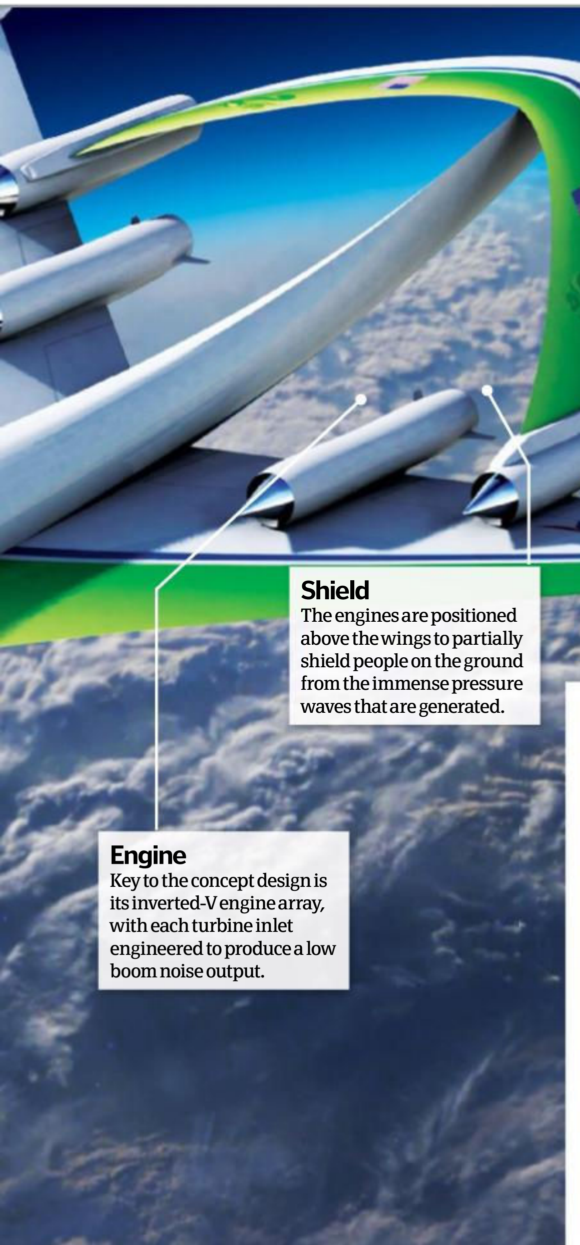
passing day, there are still major hurdles that need to be overcome – something driven by a call from NASA for companies to investigate ways to cancel out the damaging effects of sonic booms, increase fuel efficiency of the aircraft and improve the ability of supersonic jets to break through the transonic envelope (see the 'Shattering Mach 1' boxout over the page). These factors represent justa few of the many challenges of not only achieving supersonic flight, but also making it commercially viable where the old Concorde ultimately was not.

In this feature, we take a closer look at the science behind travelling at supersonic speeds as well as at some of the aircraft and advanced technology currently leading the charge against Earth's sound barrier.

The Supersonic Green Machine

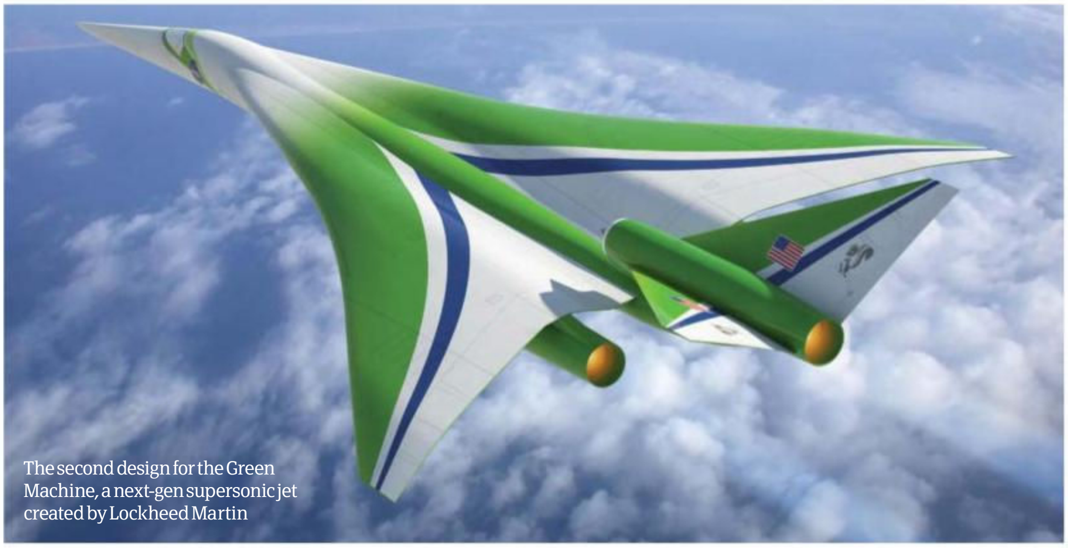
Lockheed Martin's Green Machine passenger plane offers a glimpse into the future of high-speed, eco-minded air travel

Lockheed Martin's Supersonic Green Machine recently piqued interest at NASA thanks to its inverted-V engine array. The array, which sits above the wings, has been designed to mitigate the generation of sonic booms, the loud and distinctive cracking sound heard when an object passes through the sound barrier. The positioning of the engines is not just an aesthetic choice either, but a strategic one that harnesses the wing area to effectively shield portions of the ground against pressure waves, thereby reducing the audible noise and 'boom carpet' heard on the ground. Interestingly, the design has also been developed to get as close as possible to the ideal aerodynamic form for a supersonic jet, with the fuselage closely resembling the Sears-Haack model (a cigar shape that minimises the creation of wave drag). While no concrete specifications have been released, according to Lockheed Martin and NASA, which have run model-sized trials in wind tunnels, the jet would offer speeds comparable to Concorde, but with significant reductions in fuel burn and noise output.



Shield
The engines are positioned above the wings to partially shield people on the ground from the immense pressure waves that are generated.

Engine
Key to the concept design is its inverted-V engine array, with each turbine inlet engineered to produce a low boom noise output.



The second design for the Green Machine, a next-gen supersonic jet created by Lockheed Martin

Banishing the boom

For the latest supersonic jets to become a reality, special technology is being designed to keep the noise down

Even when active, Concorde was prohibited from flying at supersonic speeds over the USA due to the impact of sonic booms. Indeed, the inability of Concorde to fly over the majority of habituated land meant it had to follow elongated and inefficient flight routes, greatly damaging its efficiency.

Eradicating these sonic booms is therefore key to any future supersonic jet being greenlit for production, with nations worldwide concerned with the 'boom carpet' (the avenue on a jet's flight path where sonic booms can be heard). Three key developments in this area have been the recent introduction of far thinner wings than Concorde, the repositioning of the engines above the wings – this effectively turns the wings into shields, diverting pressure waves away from the ground – and the creation of pressure-sculpting air inlets for the aircraft's turbines.

While no physical jet has yet to enter production, experimentation by US space agency NASA in 2011 into sonic booms confirmed that, if the new designs could adequately hide the engine outlets within a narrow fuselage, then almost all audible noise could be cancelled out.

2x © NASA; Lockheed Martin

21st Century supersonic flight

> “No other commercial supersonic jet has been introduced to the public”

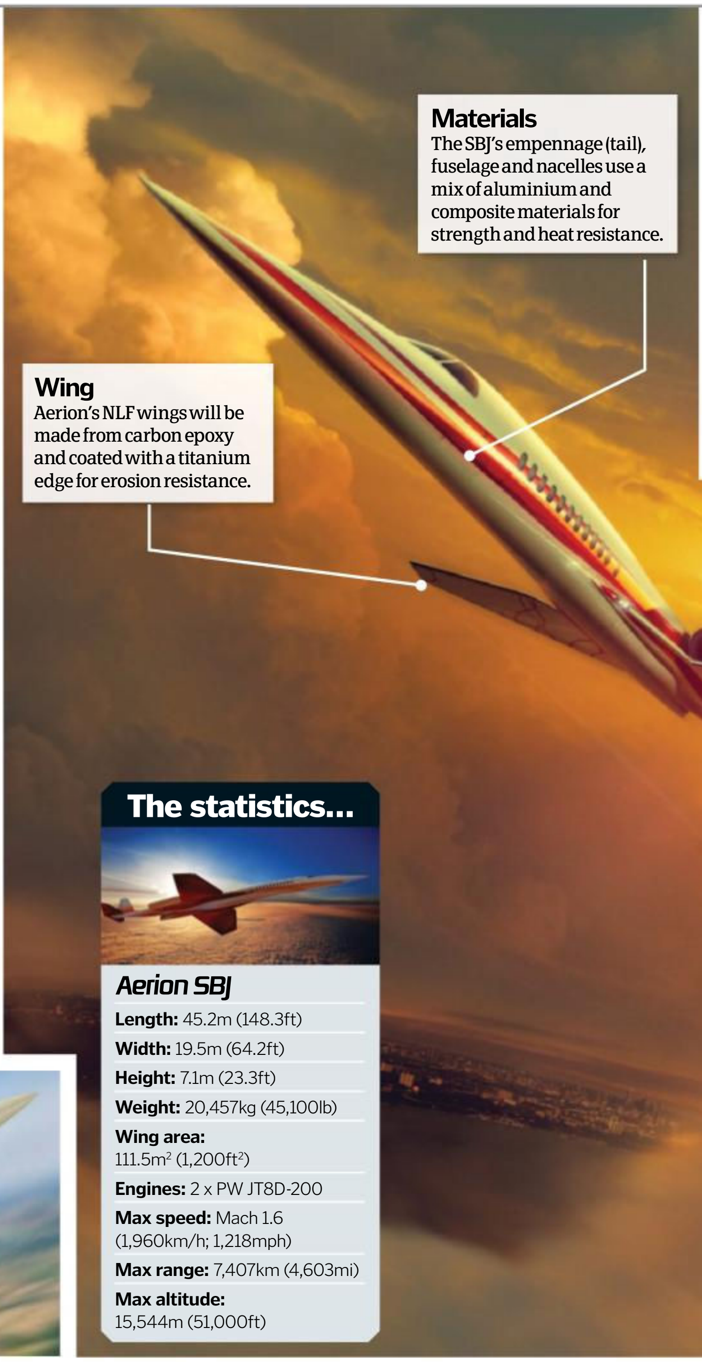
Aerion SBJ

The SBJ supersonic plane will be able to cruise at Mach 1.6, taking passengers from Paris to NYC in just over four hours

Aerion Corporation is arguably at the cutting edge of supersonic flight research, with the company collaborating closely with NASA on developing the tech necessary to introduce its Supersonic Business Jet (SBJ), a piece of kit that will be able to take passengers anywhere at over 1,900 kilometres (1,200 miles) per hour.

This ability will come courtesy of the advanced research into a technology called natural laminar flow (NLF). Laminar flow is the condition in which air in a thin region adjacent to a plane's wings stays in smoothly shearing layers, rather than becoming turbulent. This means that the more laminar the airflow, the less aerodynamic friction drag impinges on the wings, which improves both range and fuel economy.

This is possible due to the tapered bi-convex wing design, which is constructed from carbon epoxy and coated with a titanium leading edge. The partnering of this with the SBJ's aluminium composite fuselage delivers an aircraft that not only provides a range of over 7,400 kilometres (4,600 miles) and a maximum altitude of 15,544 metres (51,000 feet), but an aircraft that can do all this while sufficiently reducing fuel burn and therefore operating costs. The latter point is incredibly important as it was a primary factor that led to Concorde being scrapped.



Materials
The SBJ's empennage (tail), fuselage and nacelles use a mix of aluminium and composite materials for strength and heat resistance.

Wing
Aerion's NLF wings will be made from carbon epoxy and coated with a titanium edge for erosion resistance.

Engine
The SBJ uses a modified version of Pratt & Whitney's JT8D-200 jet engine, which is de-rated to 8,890kg (19,600lb) of static thrust.

The SBJ will be able to travel from New York to Paris in four hours and 15 minutes, almost half the time of a regular jetliner

The SBJ's cabin measures 9.1m (30ft) and allows for three dedicated seating areas

The statistics...

Aerion SBJ

Length: 45.2m (148.3ft)

Width: 19.5m (64.2ft)

Height: 7.1m (23.3ft)

Weight: 20,457kg (45,100lb)

Wing area: 111.5m² (1,200ft²)

Engines: 2 x PW JT8D-200

Max speed: Mach 1.6 (1,960km/h; 1,218mph)

Max range: 7,407km (4,603mi)

Max altitude: 15,544m (51,000ft)

4x © Aerion

The end of Concorde

Concorde was an engineering masterstroke. So why did the luxurious jetliner get shut down?

What was arguably the death knell for Concorde was the disastrous crash of Air France's Flight 4590 in 2000, which killed all 100 of its passengers, nine crew members and four people on the ground. The crash was caused by a titanium strip falling off a Continental Airlines DC-10 aircraft that had taken off minutes before the ill-fated Concorde. The strip pierced one of Flight 4590's tyres, caused it to explode and consequently sent rubber into one of the aircraft's fuel tanks. The resultant shockwave caused a major fuel leak, which then ignited due to electrical landing gear wires sparking.

Post-crash, despite Concorde being arguably one of the safest operational passenger airliners in the world, both Air France and British Airways – its only two operators – reported a steep decline in passenger numbers, leading both fleets to be decommissioned in 2003.

A British Airways Concorde taking off shortly before the jetliner's retirement

© James Gordon

KEY DATES SUPERSONIC TRAVEL

1947
Chuck Yeager (right) breaks the sound barrier for the first time in an experimental Bell X-1 rocket plane.

1953
Jacqueline Cochran becomes the first female pilot to break the sound barrier in a Canadair Sabre production jet.

1969
Concorde (right), the world's first supersonic jetliner, makes its maiden test flight.

1997
Andy Green becomes the first person to break the sound barrier on land in his ThrustSSC rocket car.

2012
Lockheed Martin and NASA reveal the Green Machine, a future supersonic jetliner that silences sonic booms.

DID YOU KNOW? *The speed of sound in air is approximately 1,225km/h (761mph)*

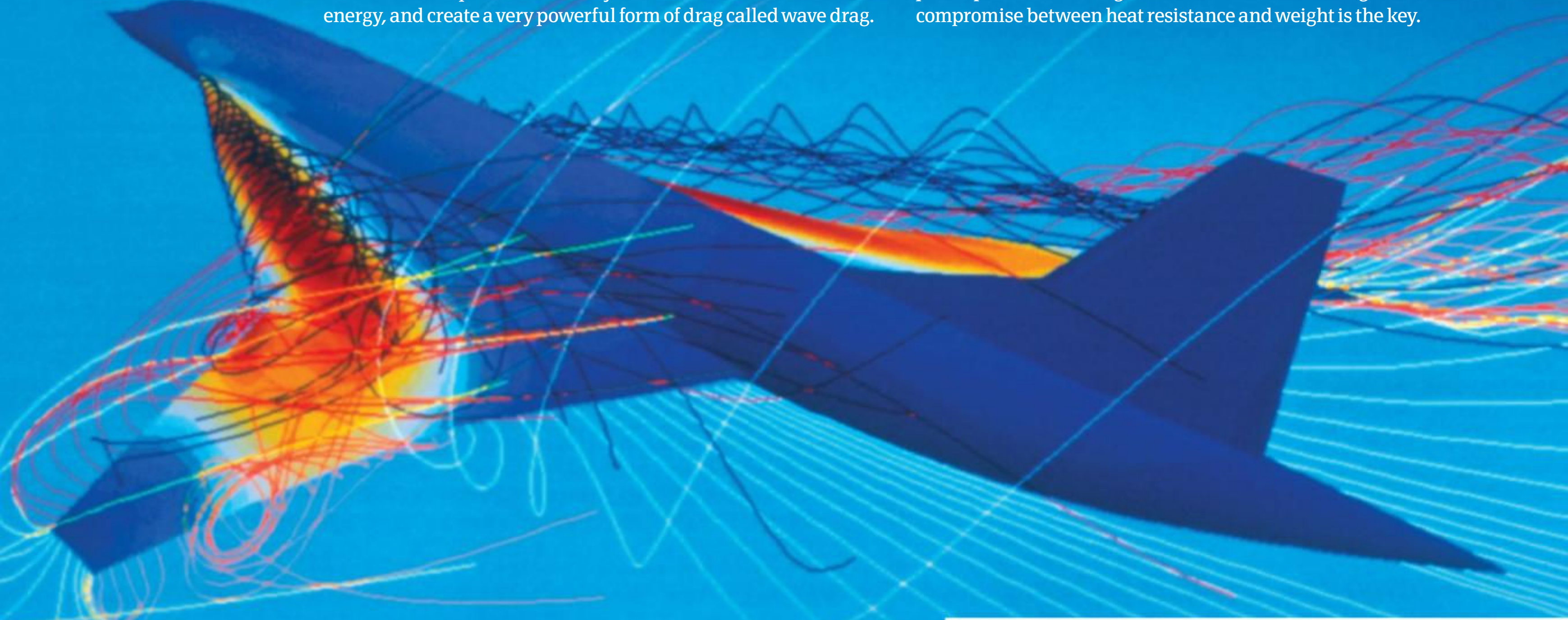
Shattering Mach 1

There is far more to creating a supersonic aircraft than simply strapping larger engines to a subsonic fuselage…

Supersonic aerodynamics are much more complex than subsonic aerodynamics for a variety of reasons, the foremost being breaking through the transonic envelope (around Mach 0.85-1.2). This is because to pass through this speed range supersonic jets require several times greater thrust to counteract the extreme drag, a factor that raises two key issues: shockwaves and heat.

Shockwaves come from the passage of air (with positive, negative or normal pressures) around the fuselage, with each part of the aircraft affecting its progress. As such, while air is bent around the thin fuselage with minimal effect, as it reaches the wings – a huge change in the cross-sectional area of the jet – it causes shockwaves along the plane's body. The resulting waves formed at these points bleed away a considerable amount of energy, and create a very powerful form of drag called wave drag. To mitigate this, any supersonic jet design must allow for a smooth-as-possible change in cross-sectional areas, with the wings fluidly curving out from the fuselage.

Heat is the other big concern. Sustained supersonic flight – as a by-product of the drag it generates – causes all of its materials to experience rapid and prolonged heat, with individual parts sometimes reaching in excess of 300 degrees Celsius (572 degrees Fahrenheit). As such, conventional subsonic materials like duraluminium (or dural) are infeasible for a supersonic jet, as they experience plastic deformation at high temperatures. To counter this, harder, heat-resistant materials such as titanium and stainless steel are called for. However, in many cases these can push up the overall weight of the aircraft, so reaching a workable compromise between heat resistance and weight is the key.



This shows the airflow over a supersonic jet's surface (including turbulence over the wing). The colour of the lines shows the air speed from red (fastest) to blue (slowest). In addition, the fuselage colour indicates its temperature, from blue (coolest) to red (hottest). Supersonic jet fuselages can be heated to over 100˚C (212˚F) by air friction

Sonic boom science

What are sonic booms and how are they generated?

Sonic booms are caused as, when an object passes through the air, it generates a series of pressure waves. These pressure waves travel at the speed of sound and increase in compaction the closer the object is to Mach 1 – approximately 1,225 kilometres (761 miles) per hour. When an object is travelling at the speed of sound (ie Mach 1), however, the sound waves become so compressed that they form a single shockwave, which for aircraft, is then shaped into a Mach cone. The Mach cone has a region of high pressure at its tip – before the nose of the aircraft – and a negative pressure at its tail, with air pressure behind the cone normal. As the aeroplane passes through these varying areas of pressure, the sudden changes create two distinctive 'booms': one for the high-to-low pressure shift and another for the low-to-normal transition.

Streams of dye are used to show the flow of water over the surface of a supersonic jet. The flow of water over the surface of the fuselage indicates what the airflow would be like over a full-sized aircraft

2x © SPL

Solar-powered aircraft

The flying machines that are fuelled only by the Sun

As the search for renewable and carbon-neutral forms of energy intensifies, solar energy is leading the way in fuelling the next generation of aircraft.

One aircraft breaking boundaries in this area is the Solar Impulse 2. This incredible machine is set to launch a non-stop, round-the-world trip powered only by the Sun. It will do this by using 72-metre (236-foot) wide wings, each of which will be carrying over 8,500 solar cells, powering four electric motors and four lithium batteries. Despite this astonishing wingspan, the entire aircraft will only weigh 2,300 kilograms (5,071 pounds), about as heavy as a large great white shark.

Another major player in the world of solar powered aviation is Solar Flight. Their newest project is Sunseeker Duo, which is the only two-seater solar-powered aeroplane in operation. It follows a similar pattern to the Solar Impulse 2, with long wings covered with solar panels and a lightweight body. Its panels have been improved to become 50 per cent more efficient than their predecessors. It can fly for 12 hours and its engine produces 25 kilowatts (33.5 horsepower) of power.

The main question with using solar power is 'what happens at night?' During the day, not all the energy is used. Enough will be stored in the batteries to allow the aircraft fly at night.

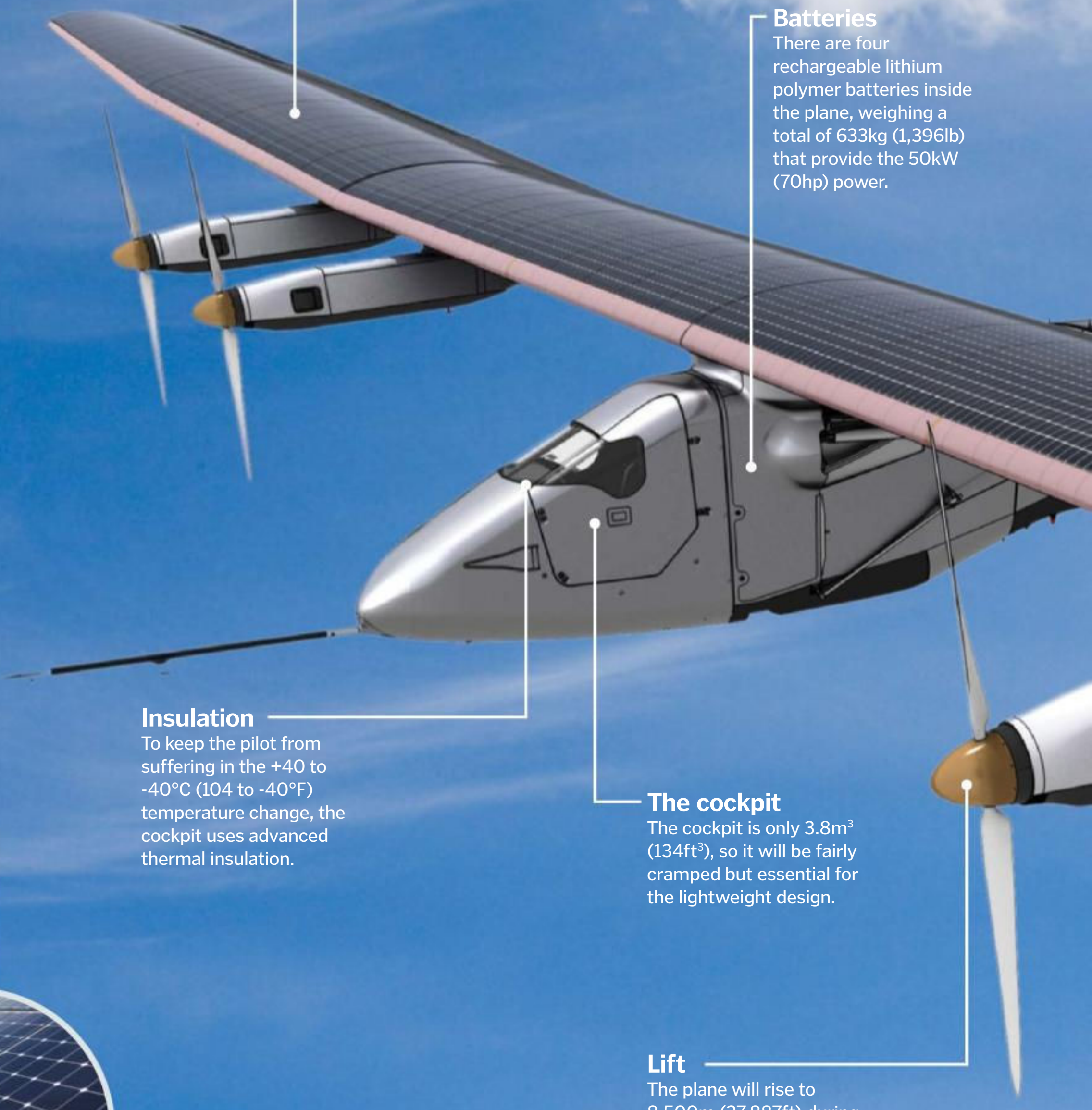
The next challenge for solar-powered aviation is to be able to carry multiple passengers, so hopefully one day soon holidaymakers will be able to use the Sun on their way to soaking it up.

How solar panels work

We have heard a lot about solar panels converting sunlight to energy, but how does that process actually work? Inside a solar panel is a number of silicon cells, placed on top of each other. One of the silicon atoms has all its electrons, while the one beneath it has a few missing. In order to restore the balance, the full silicon atom transfers electrons to the one below, but it needs light to trigger the process. Once the sunlight hits the panel, electrons are transferred from one silicon cell to the other, thus creating an electric current that powers a load.

Anatomy of a solar aircraft

How the Solar Impulse 2 gets off the ground and stays there



Wings
The wingspan of the plane is a total of 72m (236ft), stretching wider than a jumbo jet's wings.

Batteries
There are four rechargeable lithium polymer batteries inside the plane, weighing a total of 633kg (1,396lb) that provide the 50kW (70hp) power.

Insulation
To keep the pilot from suffering in the +40 to -40°C (104 to -40°F) temperature change, the cockpit uses advanced thermal insulation.

The cockpit
The cockpit is only $3.8m^3$ ($134ft^3$), so it will be fairly cramped but essential for the lightweight design.

Lift
The plane will rise to 8,500m (27,887ft) during the day to make the most of the power and then drop to 1,500m (4,921ft) at night.

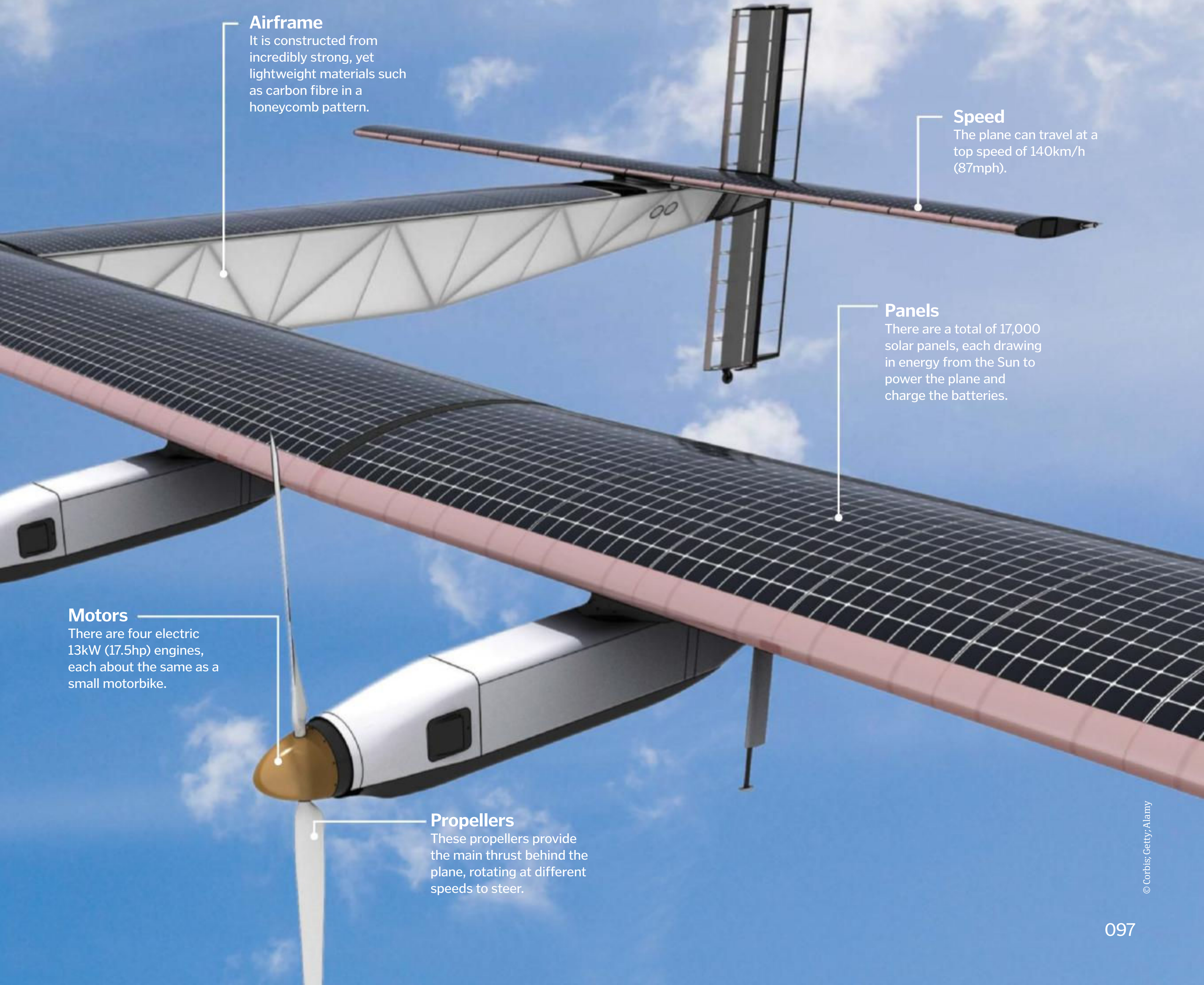
DID YOU KNOW? *In 2013, the original Solar Impulse prototype flew across the USA without a single drop of fuel*

Despite the massive wingspan, the Solar Impulse weighs about the same as two small cars

SOLARIMPULSE
HB-SIA
OMEGA
SOLVAY

Close up power

ESA's Solar Orbiter will be getting a ridiculous boost of solar energy when it takes off in 2017 as its mission is to get closer to the Sun than any probe has before, in order to take incredible pictures of the star. With its 3.1-metre x 2.4-metre (10.2-foot x 7.9-foot) sunshield, this craft will travel just 42 million kilometres (26 million miles) away from the Sun to take high-resolution images and perform experiments. It has been rigorously tested, as it will experience temperatures ranging from 520 degrees Celsius (968 degrees Fahrenheit) to -170 degrees Celsius (-274 degrees Fahrenheit). Its aim is to help scientists lean more about the inner heliosphere and how solar activity affects it, answering questions about solar winds, coronal magnetic fields and solar eruptions.



Airframe
It is constructed from incredibly strong, yet lightweight materials such as carbon fibre in a honeycomb pattern.

Speed
The plane can travel at a top speed of 140km/h (87mph).

Panels
There are a total of 17,000 solar panels, each drawing in energy from the Sun to power the plane and charge the batteries.

Motors
There are four electric 13kW (17.5hp) engines, each about the same as a small motorbike.

Propellers
These propellers provide the main thrust behind the plane, rotating at different speeds to steer.

© Corbis; Getty; Alamy

Hot-air balloons

How do these gasbags get off the ground and return to Earth safely?

A hot-air balloon consists of three basic parts: an envelope big enough to displace a large amount of air, burners beneath the envelope to heat the air inside, and a basket in which to sit back and enjoy the ride. The scientific principle that enables this lift is convection, or heat transfer.

Heating the air inside the envelope causes it to expand, forcing some of the air out of the envelope. The weight of the air inside then decreases, making the balloon lighter and giving it some lift. Once the burner has been shut off, however, the air inside cools and contracts, causing cold air to rush in from below, weighing the envelope down and causing the balloon to descend. If the burner is powered up intermittently, the balloon can maintain a pretty much constant altitude. Hot-air balloons have an upper limit because at very high altitudes the air is so thin that the lift is not actually strong enough to raise the balloon.

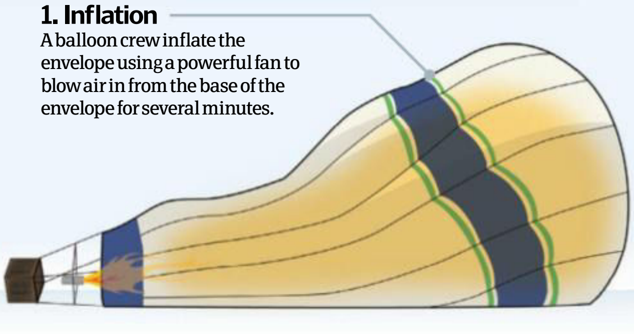
Because hot-air balloons have no real means of changing direction other than upwards and downwards, the vehicle will drift along with the wind. However, a skilled balloonist can manoeuvre horizontally by altering their altitude. You see, wind is known to blow in different directions at different heights and so the pilot can ascend or descend until they find the appropriate wind to send them in the direction they wish to travel.

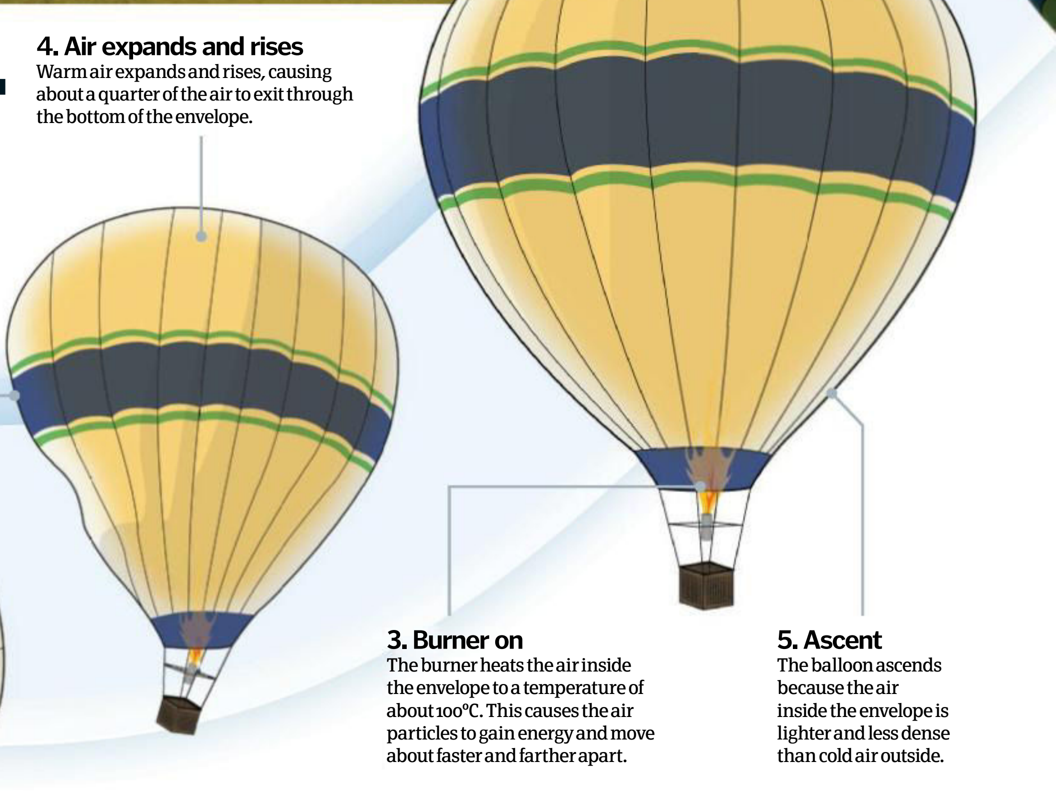
An alternative to queuing at the airport…

Envelope
Reinforced ripstop nylon fabric (also used for kites, sails and sleeping bags) is the principle material used for hot-air balloon envelopes. This lightweight fabric can also be coated with silicone to make it more hard-wearing.

What goes up…

The envelope is made from ripstop nylon


1. Inflation
A balloon crew inflate the envelope using a powerful fan to blow air in from the base of the envelope for several minutes.


2. Erection
To get the inflated envelope off the ground, the propane-fuelled burner beneath the envelope is placed at the entrance to the envelope and blasted.

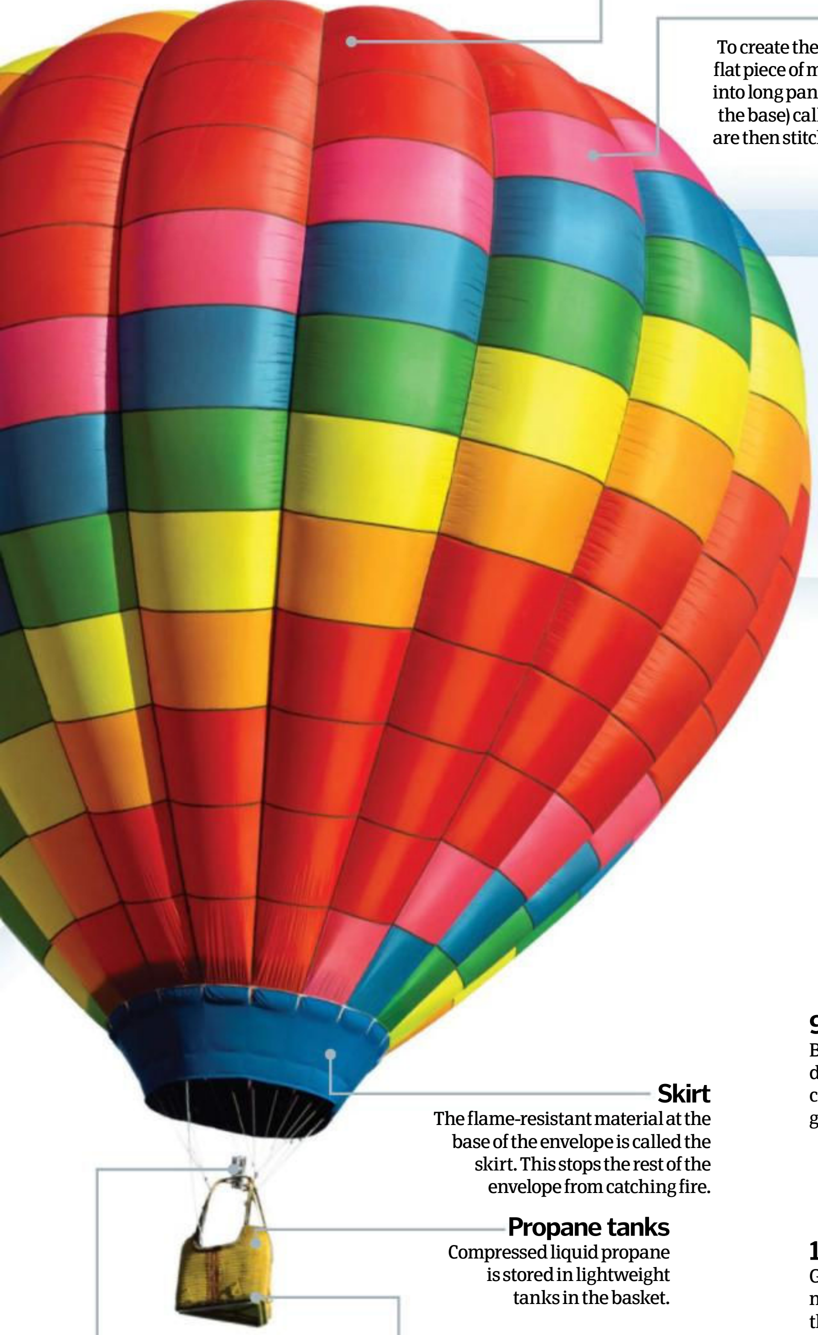
3. Burner on
The burner heats the air inside the envelope to a temperature of about 100°C. This causes the air particles to gain energy and move about faster and farther apart.

4. Air expands and rises
Warm air expands and rises, causing about a quarter of the air to exit through the bottom of the envelope.

5. Ascent
The balloon ascends because the air inside the envelope is lighter and less dense than cold air outside.

DID YOU KNOW? *To lift a weight of 1,000lb you would need nearly 65,000 cubic feet of hot air*

Turning up the heat gets you airborne…



Parachute vent
If the balloon needs to descend quickly, some colder air can enter via a parachute valve or vent in the top of the envelope controlled by a cord pulled by the pilot.

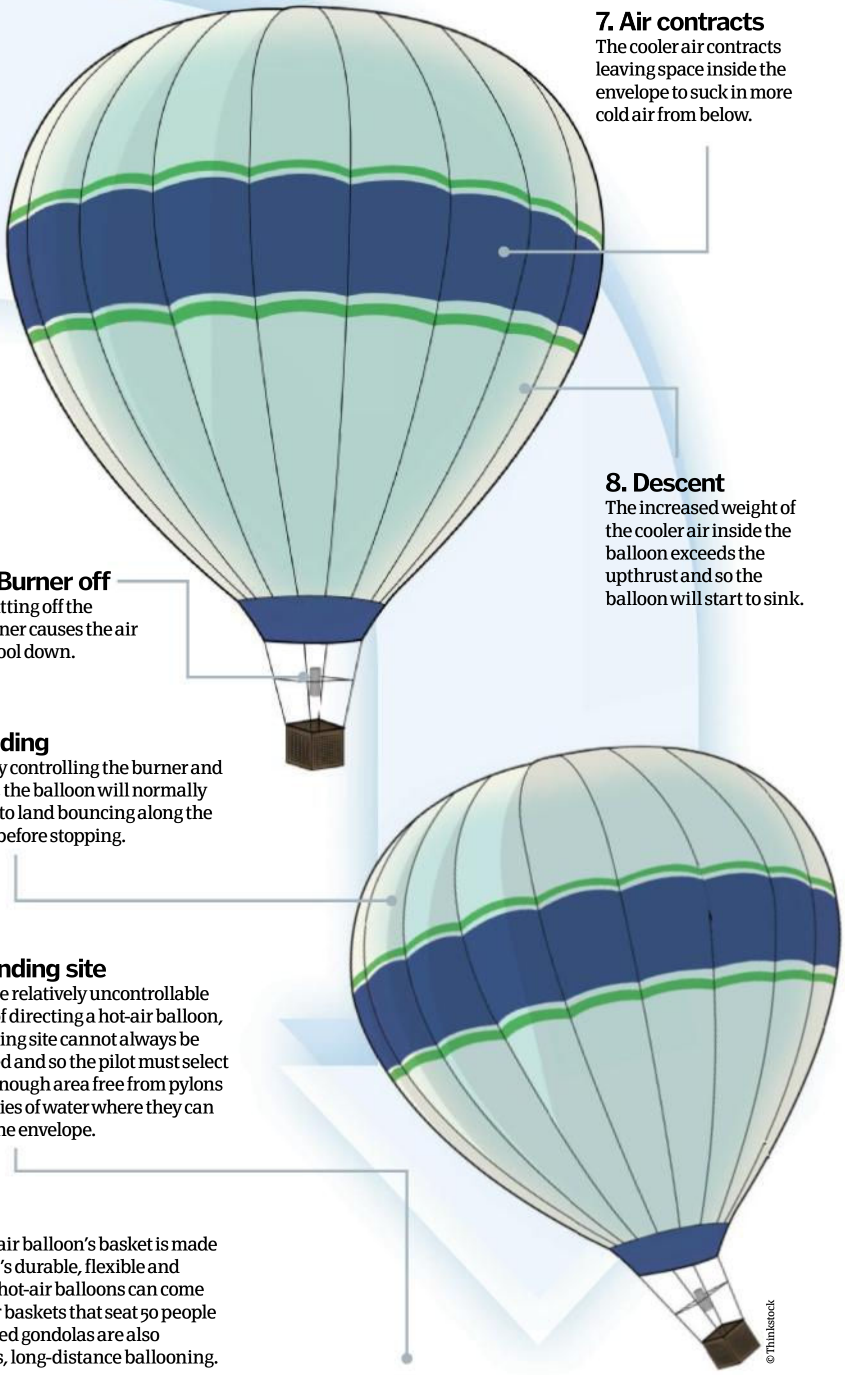
Gores
To create the balloon shape from a flat piece of material, it must be cut into long panels (from the crown to the base) called gores. These gores are then stitched together to create the shape.

Skirt
The flame-resistant material at the base of the envelope is called the skirt. This stops the rest of the envelope from catching fire.

Propane tanks
Compressed liquid propane is stored in lightweight tanks in the basket.

Burner
Liquid propane flows from the tanks through steel pipes coiled around the burner. When the balloonist triggers the burner, liquid propane flows out and is ignited by a pilot light. In the meantime this flame heats the metal pipes, turning the liquid propane into a gas that is more powerful and fuel-efficient than the liquid when it's cold.

Basket
Traditionally a hot-air balloon's basket is made of wicker because it's durable, flexible and lightweight. Today hot-air balloons can come with double-decker baskets that seat 50 people if necessary. Enclosed gondolas are also available for serious, long-distance ballooning.



6. Burner off
Shutting off the burner causes the air to cool down.

7. Air contracts
The cooler air contracts leaving space inside the envelope to suck in more cold air from below.

8. Descent
The increased weight of the cooler air inside the balloon exceeds the upthrust and so the balloon will start to sink.

9. Landing
By gently controlling the burner and descent, the balloon will normally come in to land bouncing along the ground before stopping.

10. Landing site
Given the relatively uncontrollable nature of directing a hot-air balloon, the landing site cannot always be predicted and so the pilot must select a large enough area free from pylons and bodies of water where they can lay out the envelope.

© Thinkstock

On board a cargo plane

How do freight aircraft differ from passenger planes, enabling them to transport much greater loads all over the planet?

Cargo planes – whether used in the private, military or commercial sphere – are fixed-wing vehicles that have usually been designed with haulage in mind or have been converted from standard aircraft. Passenger planes commonly have a specialised hold that can store around 150 cubic metres (over 5,000 cubic feet) of freight, found on the underside of the craft. Dedicated freight planes don't need the seats or any of the other amenities on commercial flights – that said, their design amounts to much more than a hollowed-out passenger plane.

To make the most efficient use of the space available, the floor is lined with a walkway and electronic rollers that allow prepackaged pallets to be rolled back as far as possible, without the need for a forklift. Large cargo bay doors are installed to fit bigger items through and, in some examples, like the Boeing 747-400, the nose lifts up to allow particularly large items to pass down the body of the plane. With the demands of air freight ever increasing, aircraft with huge cargo capacities like the Airbus A300-600 Super Transporter (also known as the Beluga), are becoming the norm.

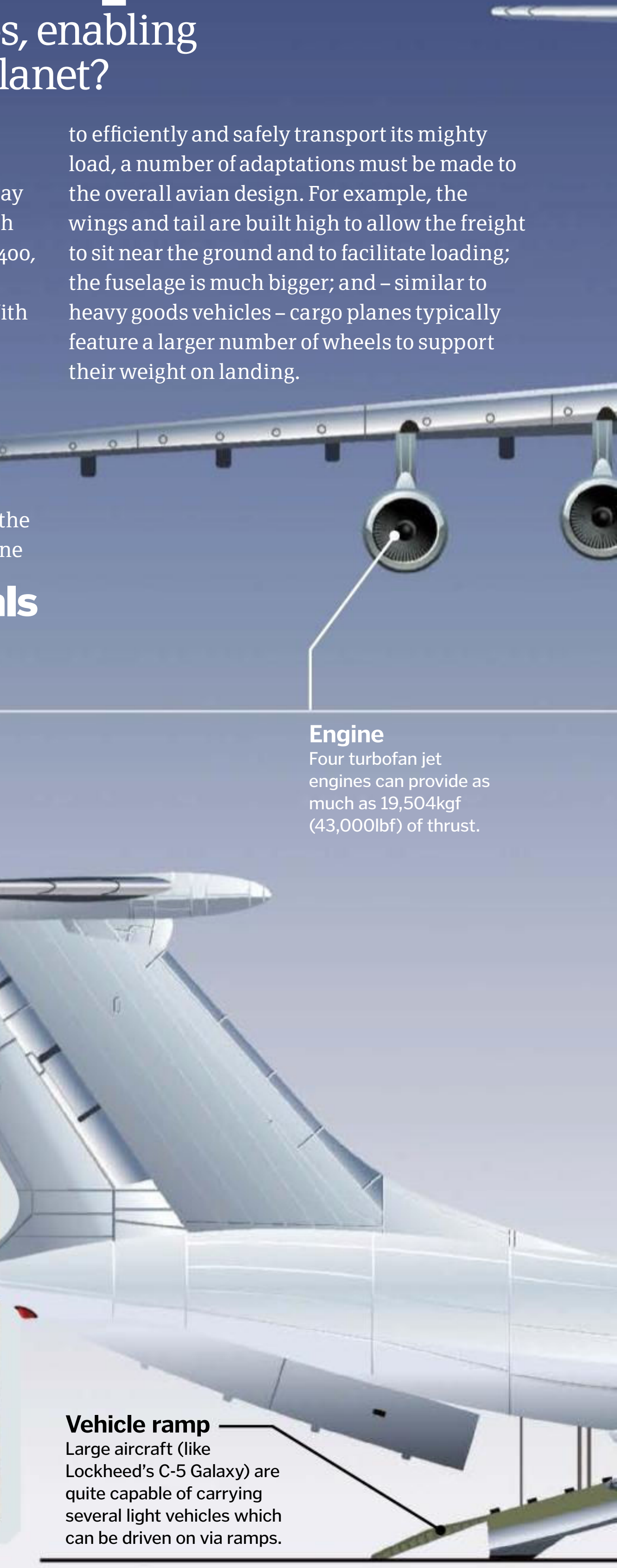
It's not enough just to increase the size of the aircraft hold though. In order for a cargo plane to efficiently and safely transport its mighty load, a number of adaptations must be made to the overall avian design. For example, the wings and tail are built high to allow the freight to sit near the ground and to facilitate loading; the fuselage is much bigger; and – similar to heavy goods vehicles – cargo planes typically feature a larger number of wheels to support their weight on landing.

Plane politics

The Xian Y-20 is a military long-range transport plane that's still in development by China, although it has recently been filmed on a short test flight. It's a similar class of aircraft as Russia's Ilyushin Il-76 or the US Boeing C-17, and though China maintains a tighter guard over its military secrets than most, it has an estimated payload in the region of 72,000 kilograms (160,000 pounds) – that's quite a bit, by any country's standards! The PLAFF (People's Liberation Army Air Force), or avian branch of the Chinese military, had long favoured the development of fighter jets over this kind of support aircraft, so that the Y-20 project was sidelined when it started in 2005. However, following the Sichuan earthquake of 2008, China was unable to effectively drop relief supplies with its small fleet of cargo planes, so the US had to assist with two C-17s. This embarrassment undoubtedly spurred the Chinese government into pushing on with the Y-20's development.

Cargo plane credentials

HIW pinpoints what a military cargo transporter needs to get the job done

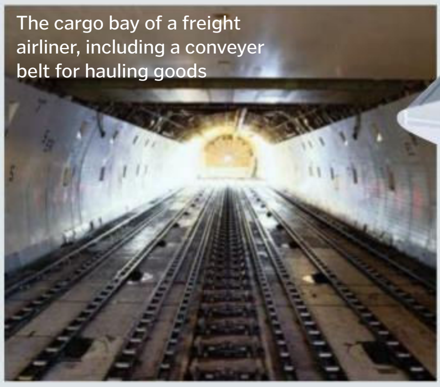


Engine
Four turbofan jet engines can provide as much as 19,504kgf (43,000lbf) of thrust.

Vehicle ramp
Large aircraft (like Lockheed's C-5 Galaxy) are quite capable of carrying several light vehicles which can be driven on via ramps.

Lightening the load

Depending on the type of cargo being carried (very large items or military vehicles may be exceptions), many cargo planes will use ULDs, or unit load devices. These allow the crew to prepackage cargo into single units that can more easily be loaded into the hold prior to the flight, saving a great deal of time. It's a similar system to that used in shipping, maximising the space used at the same time and, thus, increasing efficiency (and profits). The ULDs themselves are either robust and lightweight aluminium pallets or aluminium-floored containers with toughened plastic walls. The containers are sometimes converted into self-contained refrigeration units to store perishable goods.



The cargo bay of a freight airliner, including a conveyer belt for hauling goods

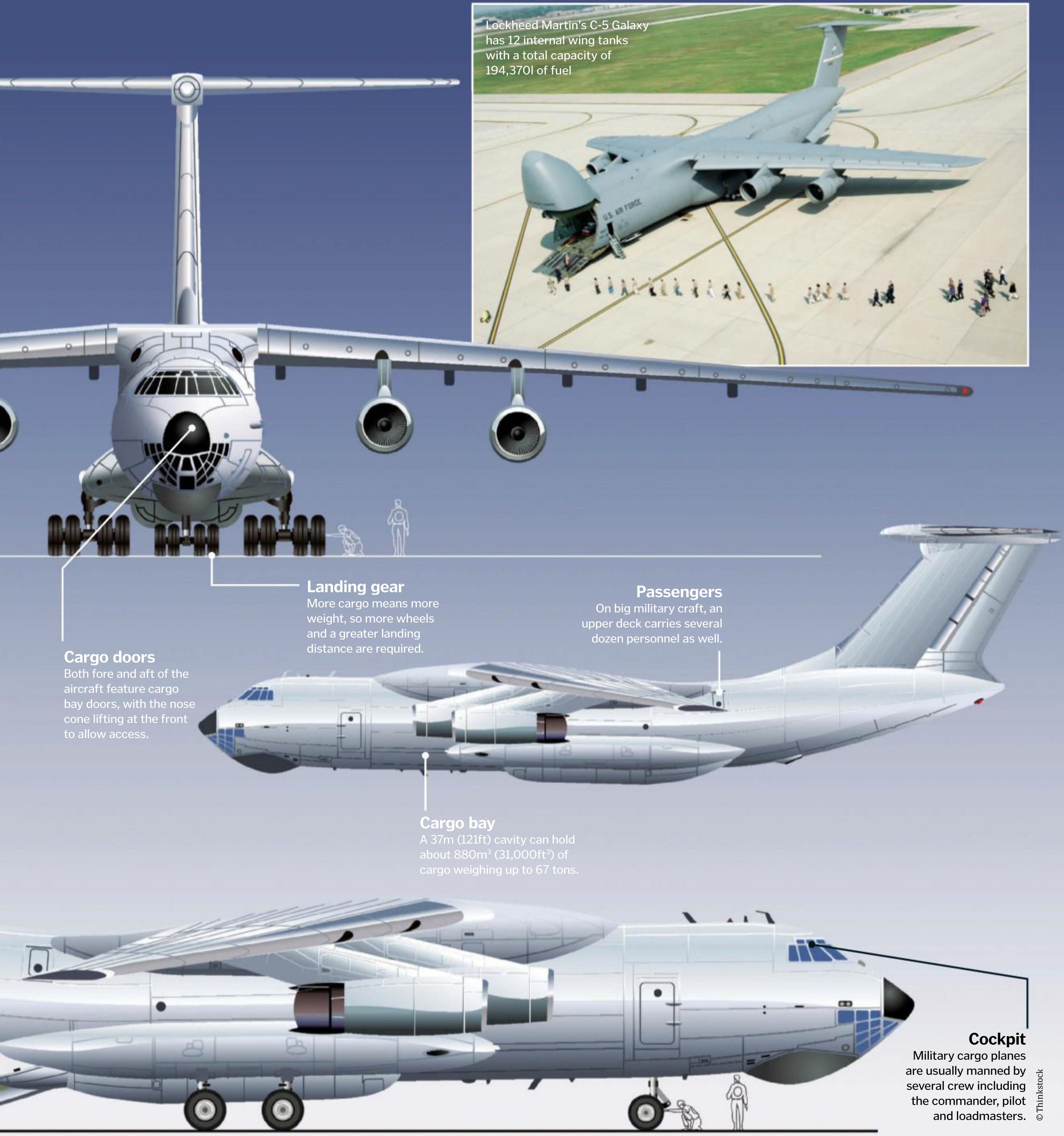
RECORD BREAKERS
LARGEST PAYLOAD

250tons

WORLD'S BIGGEST CARGO PLANE

This title goes to Russia's Antonov An-225 Mriya. It has a wingspan roughly the length of a football pitch, can carry four tanks in its cavernous hold and has space for up to 80 cars.

DID YOU KNOW? *Passenger planes have been used to carry mail since 1911 and still do to this day*



Lockheed Martin's C-5 Galaxy has 12 internal wing tanks with a total capacity of 194,370l of fuel

Landing gear
More cargo means more weight, so more wheels and a greater landing distance are required.

Passengers
On big military craft, an upper deck carries several dozen personnel as well.

Cargo doors
Both fore and aft of the aircraft feature cargo bay doors, with the nose cone lifting at the front to allow access.

Cargo bay
A 37m (121ft) cavity can hold about 880m^3 (31,000ft^3) of cargo weighing up to 67 tons.

Cockpit
Military cargo planes are usually manned by several crew including the commander, pilot and loadmasters.

© Thinkstock

Boeing 787 Dreamliner

This new jetliner promises to transform the commercial airliner industry, boasting significantly improved fuel economy and a host of next-gen features. We take a closer look…

At first glance the brand-new Boeing 787 Dreamliner appears to be nothing special. A new mid-sized jetliner that through its conventional design, standard power output and modest maximum range seems to, for the most part, blend in with the crowd. Just another commercial passenger jet introduced to a market hit severely by the worldwide recession. A multimillion pound piece of technology that changes nothing. But if you believe that, then you couldn't be more wrong…

That is because, as is common with most groundbreaking new technologies and ideas, the devil is in the details. Indeed, the Boeing 787 is arguably a slice of the future today, both literally (its service life is predicted to extend up to 2028) and metaphorically. The latter comes courtesy of it being the first aircraft to be designed within a mantra of efficiency over everything else. That's not to downplay the aircraft's numerous new improvements and technological advancements in any way – this is one of the most complex jetliners currently in operation in the skies – but in the present financial climate and arguably one that will affect the industry for years to come, this greener, cheaper and more accommodating aircraft is laying down a roadmap that others can now follow. The evidence for this? How about worldwide orders of 821 new planes from 57 operators to the tune of £93 ($145) billion?

So how is the 787 turning the dream of cheaper, more efficient air travel into a reality? The simple answer is a direct 20 per cent saving on both fuel usage and outputted emissions. The long answer is a little more complicated.

The key to the super-high performance granted by the Dreamliner lies in its adoption of a suite of new technologies and materials. Composite materials (ie carbon-fibre/reinforced carbon-fibre plastics) make up 50 per cent of the primary structure of the 787, which include both the fuselage and the wings. These are lighter, stronger and more versatile than traditional pure-metal offerings. Indeed, when this model is compared against the Dreamliner's predecessor, the Boeing 777 – read: a mere 12 per cent composite materials and over 50 per cent aluminium – you begin to grasp what a game-changer this vehicle is to the jetliner industry.

The new materials have been partnered with a completely revisited build process, which allows each Dreamliner to be produced from fewer aluminium sheets, less fasteners (an 80 per cent

5 TOP FACTS
BOEING 787 DREAMLINER

Rollout
1 The Boeing 787 Dreamliner was first unveiled on 8 July 2007 in Washington, USA. By the time of its unveiling it had already accrued 677 orders from companies worldwide.

Big brother
2 The 787 got a big brother in 2013, with a larger – read: elongated – variant of the Dreamliner first in production. This has a capacity for 290 passengers.

Fat boy
3 The initial assembly of the 787 did not go smoothly, with the aircraft coming in overweight by about 2,300kg (5,000lb). Boeing used lighter titanium to reduce this excess.

Assembly
4 Until 2011, the final assembly of all 787s was at the Boeing factory in Everett, WA. Since last year, however, the aircraft have also been put together at North Charleston, SC.

First
5 The first Dreamliner to be officially delivered was to All Nippon Airways in September 2011. ANA is one of Japan's largest airlines, operating to 35 global locations out of Tokyo.

DID YOU KNOW? *The Boeing 787 consumes 20 per cent less fuel than the similarly sized 767v*

الطيران العماني
OMAN AIR

© Boeing

More than 50 companies have worked on the 787, each connected virtually at 135 sites worldwide

© Boeing

787 cabin layouts can be split into one of three configurations, prioritising capacity or class divisions

© Boeing

reduction on the 777) and simpler drill schematics – the latter allowing a 787 to have fewer than 10,000 holes drilled in its fuselage (the 747 needed over a staggering 1 million). This saves on production costs, assembly time and streamlines the build, reducing potential points of failure, while increasing aerodynamic efficiency. In addition, more than 60 miles of copper wiring has been eliminated from the new model, again saving weight, plus streamlining the electrical infrastructure.

Talking of electronics, the Dreamliner has been designed with a state-of-the-art, fully electronic architecture, which through the replacement of all bleed air and hydraulic power sources with electrically powered compressors and pumps, extracts as much as 35 per cent less power from its engines at any one time. Further, a new electrothermal wing ice protection system – with moderate heater mats located on wing slats – improves de-icing levels and consistency significantly, again boosting aerodynamic performance. Wing lift performance is also improved thanks to the adoption of raked wingtips, which reduce the thrust needed by the engines.

These efficiencies combine with the heart of the Dreamliner: its twin next-generation, high-bypass turbofan engines. Two engine models are used on the 787 – both the General Electric GEnx and Rolls-Royce Trent 1000 – each delivering a maximum thrust of 280 kilonewtons (64,000 pounds force) and a cruise speed of Mach 0.85 (1,041 kilometres/647 miles per hour). Both engines are designed with lightweight composite blades, a swept-back fan and small-diameter hub to maximise airflow and high-pressure ratio – the latter, when complemented by contra-rotating spools, improving efficiency significantly. Finally, both engines are compatible with the Dreamliner's noise-reducing nacelles, duct covers and air-inlets. Indeed, the engines are so technologically advanced that they are considered to be a two-generation improvement over any other commercial passenger jet.

As such, contrary to initial appearances, the Dreamliner is really a wolf in sheep's clothing, delivering standard-bearing improvements, along with a vast list of incremental ones – including energy-saving LED-only lighting – that make it one of the most advanced and future-proofed jets in our skies today. And you know what is most exciting? Judging by Boeing's current substantial backlog of sales, there is a high probability that you will be flying on one of these mighty machines yourself in the very-near future.

The statistics...

Boeing 787 Dreamliner

Crew: 2

Length: 57m (186ft)

Wingspan: 60m (197ft)

Height: 17m (56ft)

Max weight: 228,000kg (502,500lb)

Cruise speed: 1,041km/h (647mph)

Max range: 15,200km (9,440mi)

Max altitude: 13,100m (43,000ft)

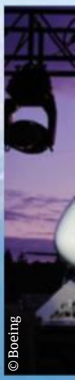
Powerplant: 2 x General Electric GEnx / Rolls-Royce Trent 1000

A General Electric GEnx high-bypass turbofan jet engine, one of two used on the Dreamliner

© Oliver Cleynen

Anatomy of the Dreamliner

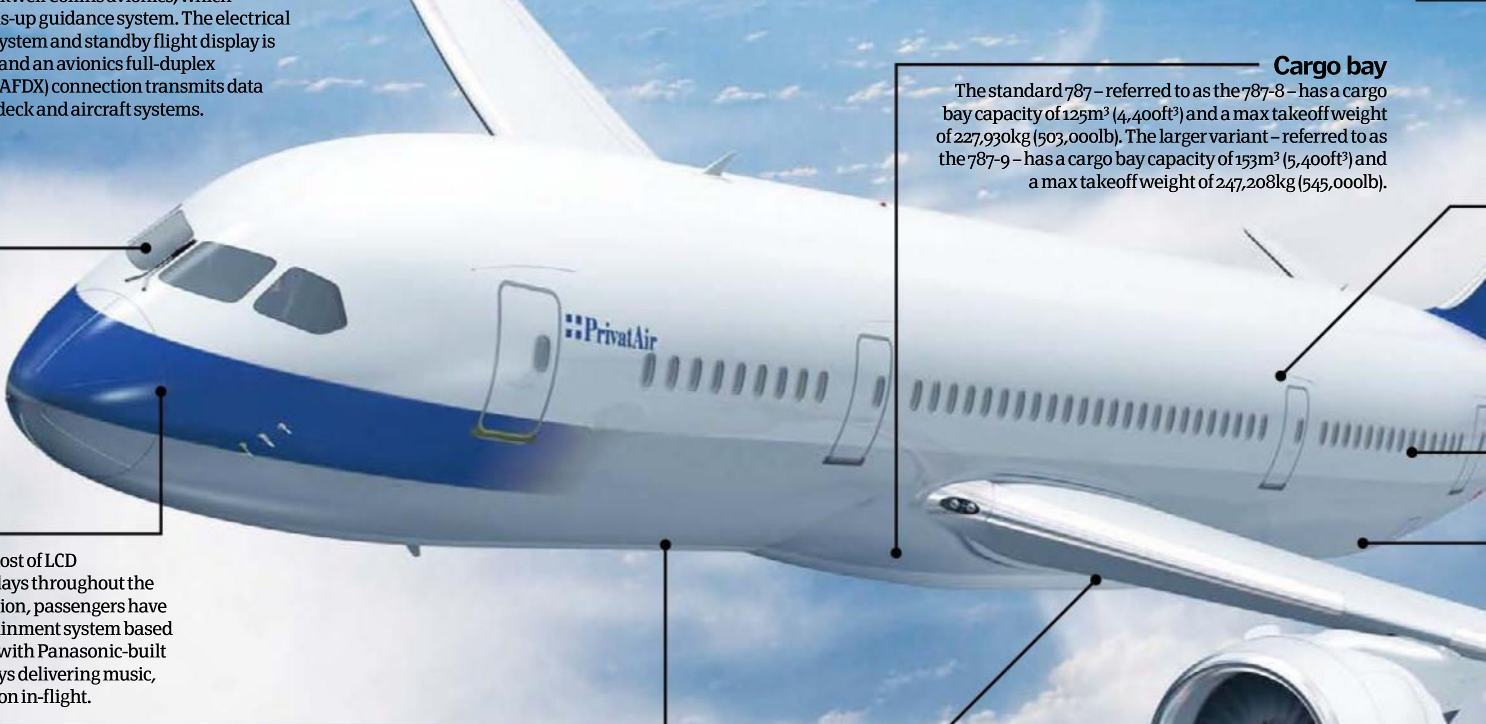
We break down a Boeing 787 to see how it outpaces, out-specs and outmanoeuvres the competition



© Boeing

© Boeing

Cockpit
The Dreamliner's state-of-the-art cockpit is fitted with Honeywell and Rockwell Collins avionics, which include a dual heads-up guidance system. The electrical power conversion system and standby flight display is supplied by Thales and an avionics full-duplex switched ethernet (AFDX) connection transmits data between the flight deck and aircraft systems.



Electronics
The 787 features a host of LCD multifunction displays throughout the flight deck. In addition, passengers have access to an entertainment system based on the Android OS, with Panasonic-built touchscreen displays delivering music, movies and television in-flight.

The first completed Dreamliner was delivered to All Nippon Airways in 2011

© Boeing

Flight systems
The 787 replaces all bleed air and hydraulic power sources with electrically powered compressors and pumps. It is also installed with a new wing ice protection system that uses electrothermal heater mats on its wing slats to mitigate ice buildup. An automatic gust alleviation system reduces the effects of turbulence too.

Wings
The 787 Dreamliner's wings are manufactured by Mitsubishi Heavy Industries in Japan and feature raked wingtips. The raked tips' primary purpose is to improve climb performance and, as a direct consequence, fuel economy.

Cargo bay
The standard 787 – referred to as the 787-8 – has a cargo bay capacity of 125m³ (4,400ft³) and a max takeoff weight of 227,930kg (503,000lb). The larger variant – referred to as the 787-9 – has a cargo bay capacity of 153m³ (5,400ft³) and a max takeoff weight of 247,208kg (545,000lb).

Engines
Two engine models are compatible with the Dreamliner: twin General Electric GEnx or Rolls-Royce Trent turbofans. Both models produce 280kN (64,000lbf) and grant the 787 a cruising speed of 1,041km/h (647mph). They are also compatible with the jet's noise-reducing nacelles, duct covers and exhaust rims.

Evolution of the jetliner

We select some of the high points in the development of the commercial jetliner

1945 Vickers VC.1 Viking
A British short-range airliner derived from the Wellington bomber, the Viking was the first pure jet transport aircraft.

1952 DH-106 Comet
The Comet was the world's first commercial jet airliner to reach production. It was developed by the de Havilland company in England.

1955 SE-210 Caravelle
The most successful first-generation jetliner, the Caravelle was sold en masse throughout Europe and America. It was built by French company Sud Aviation.

1958 Boeing 707-120
The first production model of the now-widespread 707 series, the 707-120 set a new benchmark for passenger aircraft.

1961 Convair 990
A good example of a narrow-body jetliner, the 990 offered faster speeds and greater passenger-holding capacity.

1976 Aérospatiale-BAC Concorde
A standout development in the second generation of jetliners, the Concorde delivered supersonic, transatlantic flight – something unrivalled even to this day.

HEAD 2 HEAD AIRLINER CAPACITY

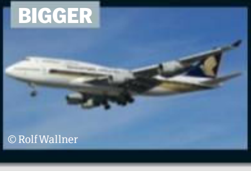
BIG

© Boeing

1. Boeing 787-9

The larger Dreamliner, which is set to be introduced in 2013, can seat up to 290 passengers when it is configured for highest seat quantity.

BIGGER


© Rolf Wallner

2. Boeing 747-400

A significant redevelopment of the 747, the 747-400, when specced out for max number of seats, can carry up to 524 passengers.

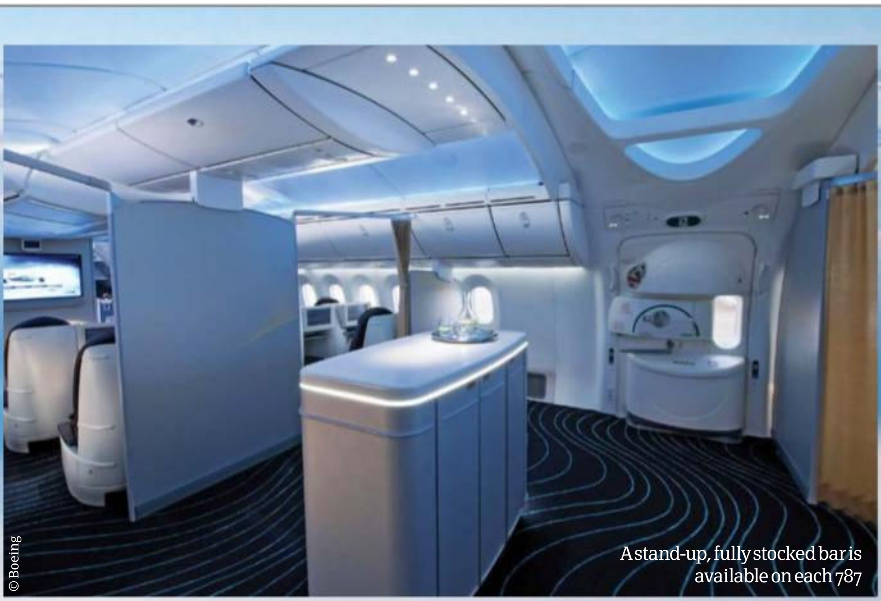
BIGGEST

© Singapore Airlines/Altair78

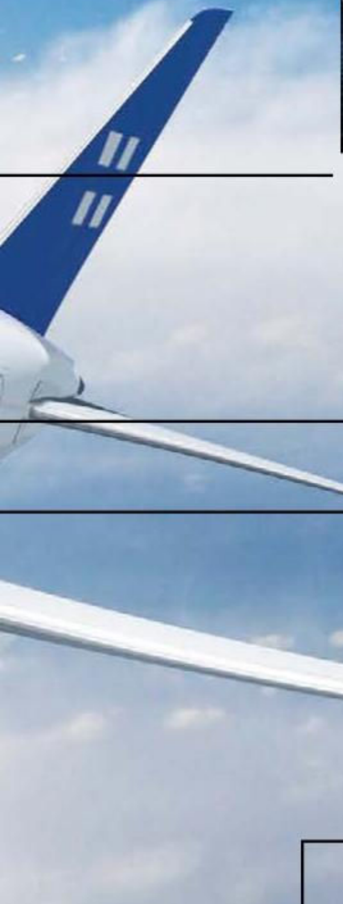
3. Airbus A380

So big that a new term had to be coined in order to classify it – superjumbo – the A380 has two decks and can carry up to a monumental 853 people!

DID YOU KNOW? To date, over 800 Boeing 787 Dreamliners have been ordered by airlines all around the world


© Boeing

A stand-up, fully stocked bar is available on each 787



Amenities

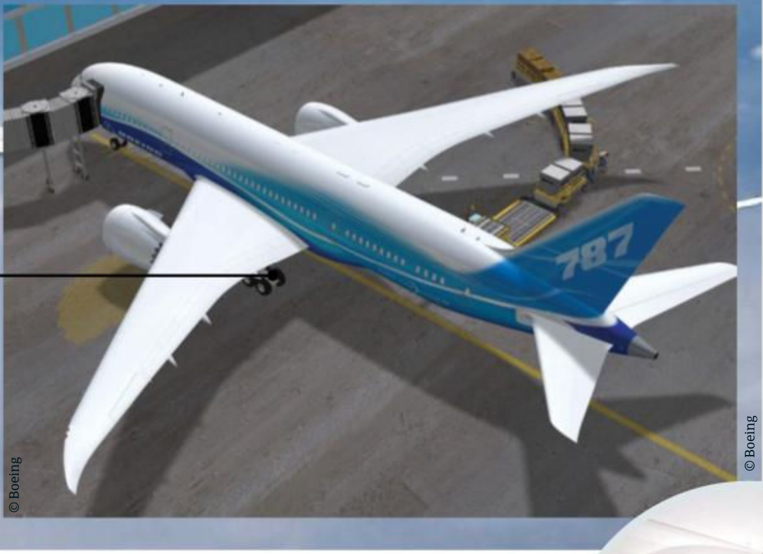
When on board passengers are offered roomier seats (across all classes), larger storage bins, manually dimmable windows, a stand-up bar, gender-specific lavatories and an on-demand entertainment system. First-class passengers receive a complimentary in-flight meal and, on international flights, fully reclinable seats for sleeping.

Cabin

The standard 787 is designed to seat 242 passengers across a three-class arrangement, with 182 seats in economy, 44 seats in business and 16 seats in first. Cabin interior width rests at 5.5m (18ft) and on either side is lined with a series of 27 x 47cm (11 x 19in) auto-dimming windows.

Fuselage

The 787 is constructed from 80 per cent composite materials (carbon fibre and carbon-fibre reinforced plastic) by volume. In terms of weight, 50 per cent of the materials are composite, 20 per cent aluminium, 15 per cent titanium, 10 per cent steel and 5 per cent other.


© Boeing

© Boeing

Compatibility

The 787 Dreamliner is designed to be compatible with existing airport layout and taxiing setups. As such the 787 has an effective steering angle of 65 degrees, allowing it to rotate fully within a 42m (138ft)-wide runway. It also has a 32m (100ft) tyre edge-to-turn centre ratio.

2x © Boeing

Train to gain

Boeing has gone the extra mile to produce a complete package with the 787 Dreamliner, offering state-of-the-art simulation facilities for pilots to get up to speed

Potential 787 pilots can utilise Boeing's revolutionary full-flight simulator to train for real-world flights and specific context-sensitive scenarios. Currently there are eight 787 training suites at five Boeing campuses worldwide, located from Seattle through to Tokyo, Singapore, Shanghai and on to London Gatwick. The simulators, which are produced by French electronic systems company Thales, include dual heads-up displays (HUDs) and electronic flight bags (EFBs), and are designed to train pilots to become proficient in visual manoeuvres, the instrument landing system (ILS) and non-ILS approaches. Further, missed approaches using integrated specialist navigation, non-standard procedures with emphasis on those affecting handling characteristics, plus wind shear and rejected takeoff training can also be undertaken.

All of the training simulators are approved by the US Federal Aviation Administration (FAA), making them officially some of the most advanced training suites around right now.

Pilots and potential pilots can train at eight simulators worldwide

1986 **Fokker 100**

The Fokker 100 was a short-haul specialist that carried up to 100 passengers. Domestic and short-range international flights were its remit.

1994 **Boeing 777**

The first computer-designed commercial jetliner, the 777 delivered a vast 300-seat capacity and range (17,370km/10,793mi). It became a mainstay of airlines worldwide.

2005 **Airbus A380**

Since its launch in 2005 the Airbus has been the largest passenger aircraft in the world. The A380 has two decks and, when specced out for all economy-class seating, can carry 853 passengers.

2011 **Boeing 787 Dreamliner**

The most fuel-efficient jetliner of its class, the 787 has been designed to reduce the cost of air travel, while delivering a range of next-gen tech.

Gliders

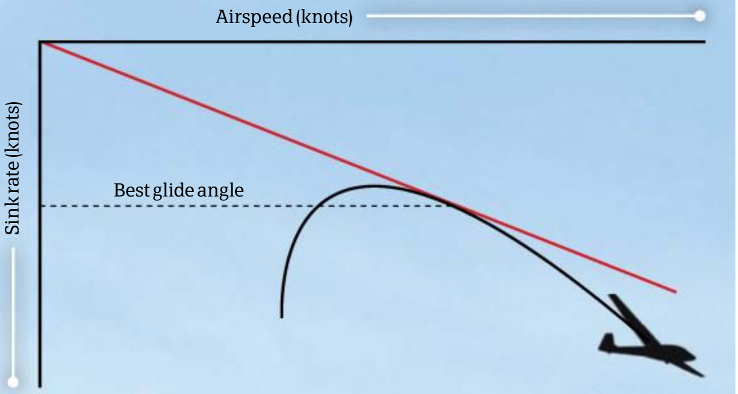
How do these engineless aircraft stay airborne?

Gliders work by maximising the dynamic properties of air to remain airborne for long periods of time. To do this they optimise their lift-to-drag (L/D) ratio – the amount of lift generated by a wing or vehicle, divided by the drag it creates by moving through the air – by extending the surface area of their lifting surfaces, ie their wings, streamlining their physical construction and utilising the lightest possible construction materials.

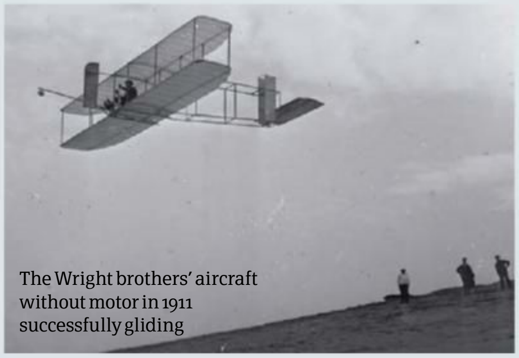
The glide ratio – the distance a glider falls for the distance it travels forward – of any glider is also reliant on its airspeed and the prevalence of rising air in the aircraft's vicinity. For example, if a glider is too light then its fall rate will be low but its travel distance forward will also be low, meaning high speed and long distance glides are impossible, as it will never reach the next area of lift. However, if a glider is weighted correctly, then the polar curve of distance travelled to distance fallen is optimised, carrying the glider between areas of uplift.

A trainer and pupil in a dual-seated trainer glider

> "Weighted correctly, the polar curve of distance travelled to distance fallen is optimised"



Experiments with gliding



The Wright brothers' aircraft without motor in 1911 successfully gliding

Gliding isn't a new pursuit of humans, although it only reached substantial success in the 20th and 21st Centuries. In fact, the first record of someone attempting to glide through the air occurs in a 17th Century account of a 9th Century attempt by Abbas Ibn Firnas of Cordoba, Spain. Unfortunately for Firnas – who was a respected polymath and inventor – the attempt was reliant on covering himself with vulture feathers and ended in bad back injuries. Where Firnas failed, though, the Wright brothers succeeded, and in 1911 they successfully glided in a modified, engineless variant of their famous aircraft. Since then the engineless glider has evolved into the sleek, streamlined aircraft we see today.

5 TOP FACTS GLIDERS

1 Recreational
Modern gliders were developed post World War Two, mainly by enthusiasts just to have fun during their time off work. Back then they were made primarily out of wood, not fibreglass.

2 Tow
Gliders were used in the Second World War to drop soldiers and equipment into war zones. The gliders would be towed half the way and then left to glide to a set drop-off point. They were considered expendable.

3 Cheat
Not all gliders are engineless, with many fitted with one to allow them to take-off on their own, removing the need for them to piggyback on another aircraft in order to get airborne.

4 Boom
The principles of gliding have been extrapolated to the armament industry, where numerous companies make gliding bombs designed to travel great distances without needing any propellant.

5 Training
Many gliders are used by instructors to educate amateur pilots in the basic principles of flight before they are given an engined aircraft. Trainer gliders contain a dual-seated cabin.

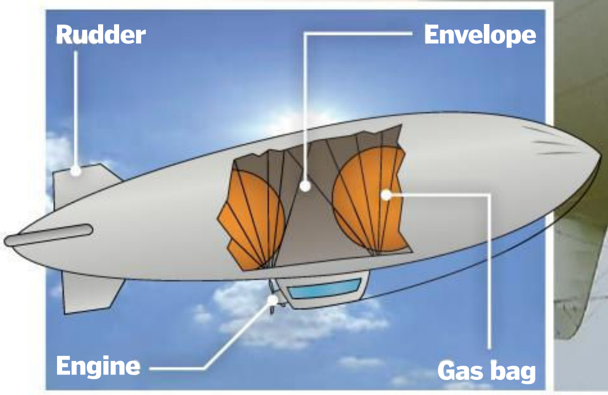
DID YOU KNOW? *The Perlan project is attempting to reach 90,000 feet with an engineless aircraft*

Inside a blimp

Graceful forms of transport that are also often used for advertising and as camera platforms

Blimps keep their shape purely through the pressure of the gas inside their main hull and changes in this pressure are managed by ballonets. These are bags of pressurised air which are also located inside the main envelope and are inflated or deflated to maintain the external shape.

The envelope itself is often made of man-made materials, with Mylar and polyester being common. Within the envelope – the blimp's outer skin – there's a second skin, commonly made from polyurethane, called the bladder. This is where the lifting gas, most commonly helium, is located. The gondola, where the passengers and crew are housed and where the blimp is controlled from, is often made of aluminium to minimise the weight of the gondola and maximise lift. Blimps are best known as platforms for advertising and tend to operate between 300 and 900 metres. However, they can operate up to 3,000m off the ground.



Modern blimps often sport reinforced noses and ducted fans to aid steering

The Perlan Project

How the Perlan 2 plans to soar to the edge of space

Gliders can soar without the need for engines because of currents of air around the plane that are rising faster than the glider is sinking. A good source of these updrafts is when wind strikes the side of a tall mountain. This creates a standing wave that ripples across the mountain range, and gliders are able to hang in this rising current almost indefinitely.

Mountain waves don't normally extend above ten kilometres because winds can't cross the boundary between the troposphere (the lowest layer of Earth's atmosphere) and the stratosphere – the edge of space. But there are a few places in the world where this rule is broken. In the far south of Patagonia, in Argentina, updrafts from the Andes combine in late summer and early autumn with high altitude winds, forming a jet stream known as the polar night jet.

This year, the Perlan 2, a non-profit research aircraft currently funded by Airbus, will ride this wave to soar to heights of over 27 kilometres. At that altitude it will be above 98 per cent of the Earth's atmosphere, and it will break the altitude record for sustained flight previously set by the SR-71 Blackbird spy plane.

The Perlan 2 has a 25.6m wingspan, but weighs just 500kg – less than seven people

© WIKI

On board Air Force One

Transporting the US president is no small task, requiring specialised aircraft that can respond to a variety of threats and situations

Air Force One is the call sign used to designate aircraft specially fitted out to carry the president of the United States while on official business. Currently two planes carry the Air Force One name – both customised versions of the Boeing VC-25A jetliner that have been in service since 1990.

Appearing like a standard airliner on the outside, Air Force One is in fact an incredibly complex aircraft, decked out with a number of hi-tech facilities that make it suitable for carrying arguably the most powerful person on the planet. Over its 372 square metres (4,000 square feet) of floor space, these include a surgery-class medical bay, a communications suite that can act as a command centre for military operations, plus a fully equipped office with satellite phone and wireless internet connection. There are also a hotel-style presidential suite capable of housing the First Family with ease, a press cabin for resident photographers and journalists, a large conference room, as well as a series of other cabins for guests, flight staff and security.

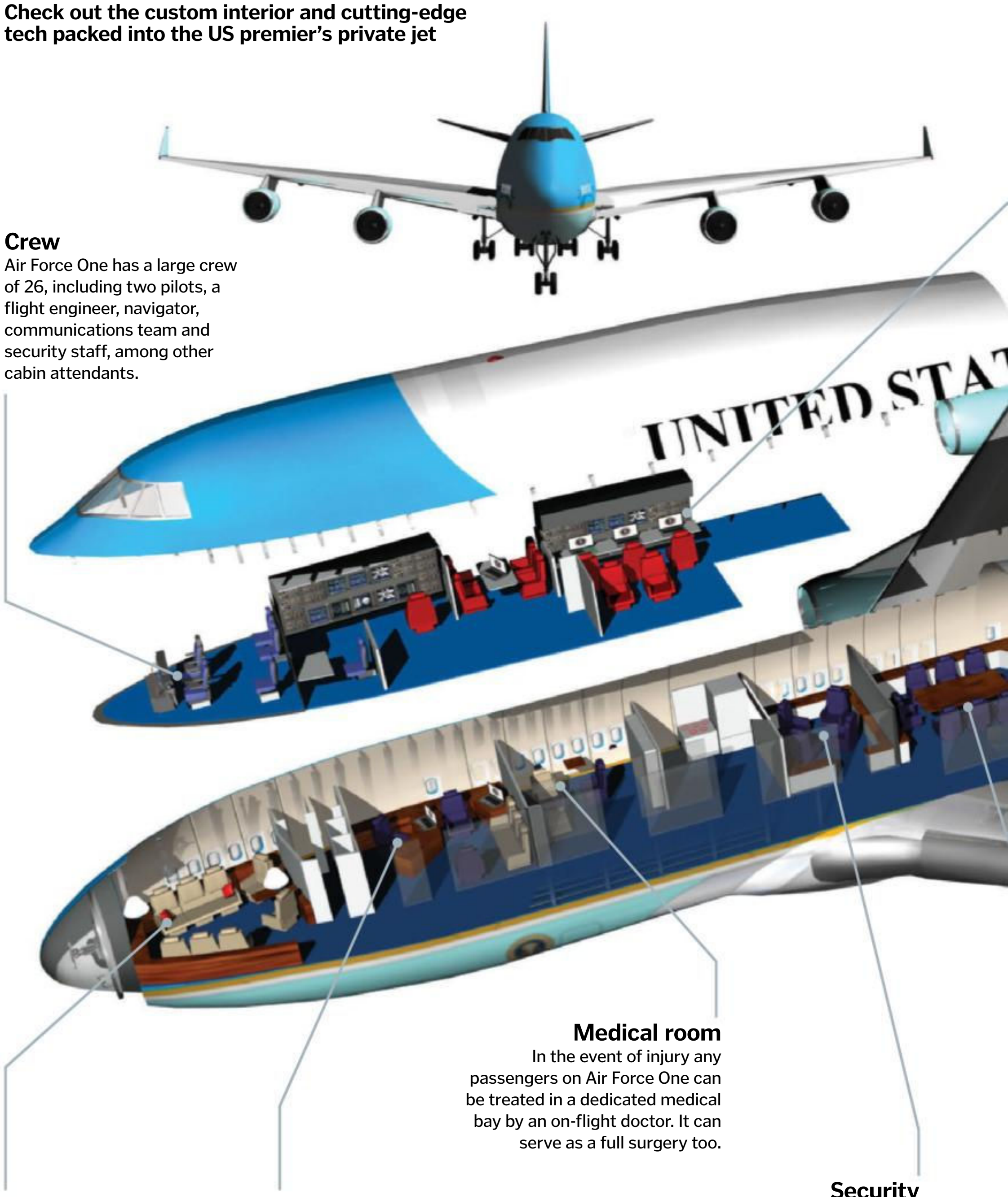
Air Force One is powered by four General Electric CF6-80C2B1F turbofan jet engines, which each deliver a substantial thrust of around 25,500 kilograms-force (56,200 pounds-force). Together, these grant Air Force One a maximum speed of 1,014 kilometres (630 miles) per hour, which, when combined with its cavernous fuel tanks, allow the president and retinue to travel anywhere within a 12,550-kilometre (7,800-mile) range fairly rapidly and without having to refuel.

If for any reason Air Force One needed to remain airborne past that distance – for example, in the event of nuclear war – then a fuel top-up can be handled during flight, as the VC-25A has a refuelling receptacle built in.

There are over 85 telephones and multi-frequency radios on board, with a staggering 383 kilometres (238 miles) of electrical wiring connecting all the various systems. Both the flight deck and communications centre, as well as every other electrical system on the aircraft, are electromagnetically shielded to prevent them from being taken out by electromagnetic pulses generated by a nuclear blast.

The plane fit for a president

Check out the custom interior and cutting-edge tech packed into the US premier's private jet



Crew
Air Force One has a large crew of 26, including two pilots, a flight engineer, navigator, communications team and security staff, among other cabin attendants.

Medical room
In the event of injury any passengers on Air Force One can be treated in a dedicated medical bay by an on-flight doctor. It can serve as a full surgery too.

Presidential suite
This has all the amenities of a high-class hotel room, allowing the US premier and his family to relax or sleep during long-haul flights.

President's office
Despite travelling, more often than not the US president needs to work while flying. This is made possible by a fully kitted-out office area equipped with satellite phone.

Security
Members of the US Secret Service follow the president at all times, including on Air Force One. They are assigned their own cabin and security positions throughout the aircraft.

5 TOP FACTS
AIR FORCE ONE

Sacred Cow

1 The first presidential aircraft was introduced in 1945 and was a converted C-54 Skymaster. It was nicknamed the Sacred Cow and carried Roosevelt and Truman.

The one and only

2 The 'Air Force One' call sign was created in 1953 after a presidential plane carrying Eisenhower entered the same airspace as a commercial airliner using the same name.

Previous owners

3 Ex-US presidents also sometimes travel on Air Force One to large state occasions, such as in 1981 when Nixon, Ford and Carter all flew to Cairo, Egypt, for a funeral.

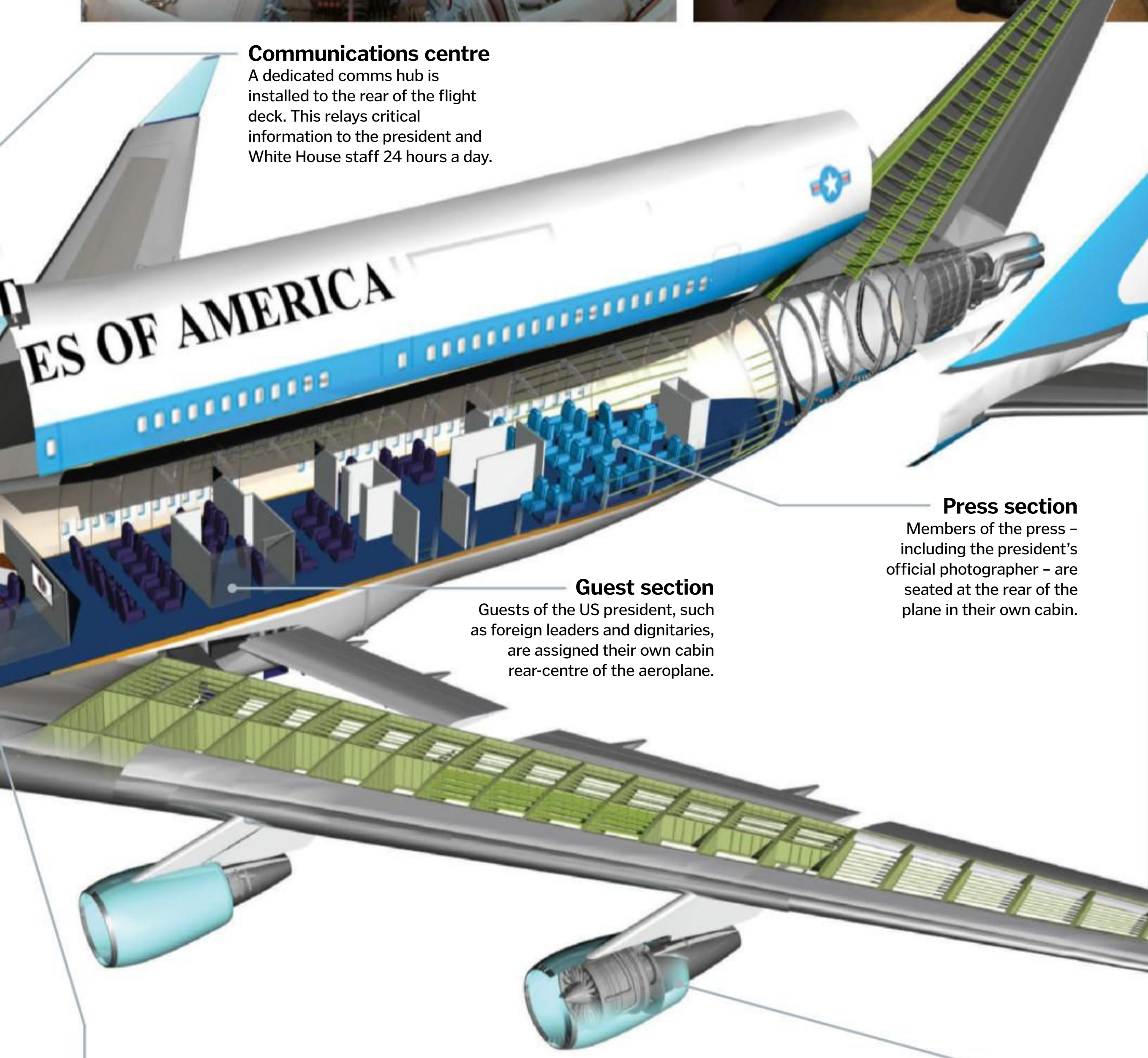
Shooting some hoops

4 In March 2012 President Barack Obama invited the British Prime Minister David Cameron to fly on Air Force One to a basketball game taking place in Ohio.

The new model

5 The two VC-25As currently in use by the US president are set to be replaced in 2017 with three new jetliners. These will either be Boeing 747-8s or Boeing 787 Dreamliners.

DID YOU KNOW? *Air Force One isn't actually a plane but a unique call name to distinguish an aircraft carrying the US premier*



Communications centre
A dedicated comms hub is installed to the rear of the flight deck. This relays critical information to the president and White House staff 24 hours a day.

Press section
Members of the press – including the president's official photographer – are seated at the rear of the plane in their own cabin.

Guest section
Guests of the US president, such as foreign leaders and dignitaries, are assigned their own cabin rear-centre of the aeroplane.

Conference room
In the event of a major incident – such as a nuclear attack – the president along with his chiefs of staff can convene in Air Force One's conference room to discuss tactical options and any intel.

Powerplant
The VC-25A is powered by four General Electric CF6-80C2B1F turbofans, each capable of outputting 25,493kgf (56,202lbf) of thrust. These grant the aircraft a top speed of 1,014km/h (630mph).

The statistics...

Air Force One

Crew: 26

Capacity: 102

Length: 70.7m (232ft)

Wingspan: 59.6m (196ft)

Height: 19.3m (63.5ft)

Powerplant: 4 x General Electric CF6-80C2B1F turbofans

Thrust per engine: 25,493kgf (56,202lbf)

Max speed: 1,014km/h (630mph)

Max altitude: 13,746m (45,100ft)

Max range: 12,550km (7,800mi)

© Alex Pang; Corbis

How to fly a helicopter

Find out what it takes to fly these amazing aircraft

Piloting this incredible piece of engineering is no mean feat for anyone. Immense mental and physical co-ordination is required; the ability to use each hand and foot independently to operate the flight controls is a prerequisite for any prospective pilot. This means training to become a helicopter pilot takes a significant amount of time, money, training and dedication. Typically more than 1,000 registered flying hours and numerous written exams are needed if you want to fly a helicopter commercially.

Advancements in helicopter technology

A number of recent advancements have improved on the existing helicopter design. One of these is the no-tail rotor, or NOTAR. This functions to solve two commonly encountered problems; namely the noise made by the tail rotor and the ease with which it can be damaged.

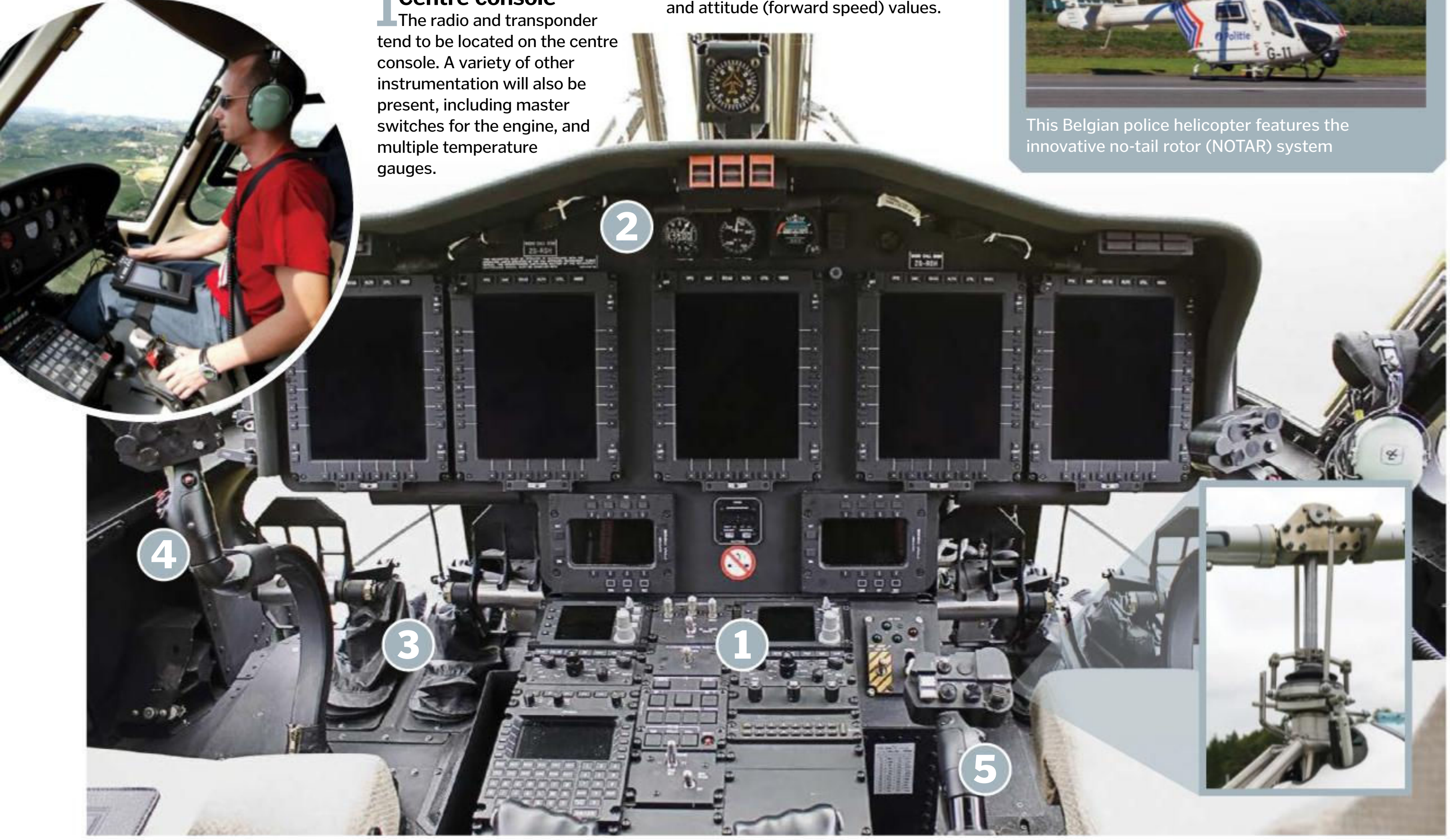
It works by blowing spent air from the helicopter's main rotor down the tail boom. Slots located on the tail boom allow the air to escape, producing a sideways force that works to oppose the torque generated by the main rotor. By varying the amount of air expelled, this can also aid directional control.

A second engine is also being fitted to some helicopters, which functions as a fail-safe if the main engine were to stop working. Either engine is capable of keeping the aircraft airborne, enabling the pilot to land safely in the event of an engine malfunction.

This Belgian police helicopter features the innovative no-tail rotor (NOTAR) system

Inside the cockpit

Learn how these controls enable a pilot to manoeuvre a helicopter



1 Centre console

The radio and transponder tend to be located on the centre console. A variety of other instrumentation will also be present, including master switches for the engine, and multiple temperature gauges.

2 Instrument panel

Similar to an aeroplane, there are a number of instruments that need constant monitoring while airborne, including speed indicators, as well as the altitude (height) and attitude (forward speed) values.

3 Anti-torque pedals

Located at the front of the cockpit are two pedals, which control the tail rotor. Operating the pedals causes a lateral change in direction, and is used to combat the torque created by the main rotors during takeoff, which causes the helicopter to turn.

4 Cyclic-pitch lever

Sitting between the pilot's legs, the cyclic-pitch lever works to tilt the aircraft forwards, backwards or side-to-side. It tilts the rotor disc in the desired direction of flight, changing the angle of the rotor blades to alter the helicopter's direction.

5 Collective-pitch lever

This works to move the aircraft up and down and is used during the helicopter's takeoff. When engaged, a collective change is imparted on the pitch of all the craft's rotor blades, by changing the angle of the swashplate (inset image). The throttle is also located here, which controls the engine's power.

© Richair/Mikhail Starodubov/Patrick Allen/Dreamstime

DID YOU KNOW? *In 1936 the Focke-Wulf Fw 61 became the first operational helicopter*

The AirBoard

Meet the smallest one-person aircraft in the world

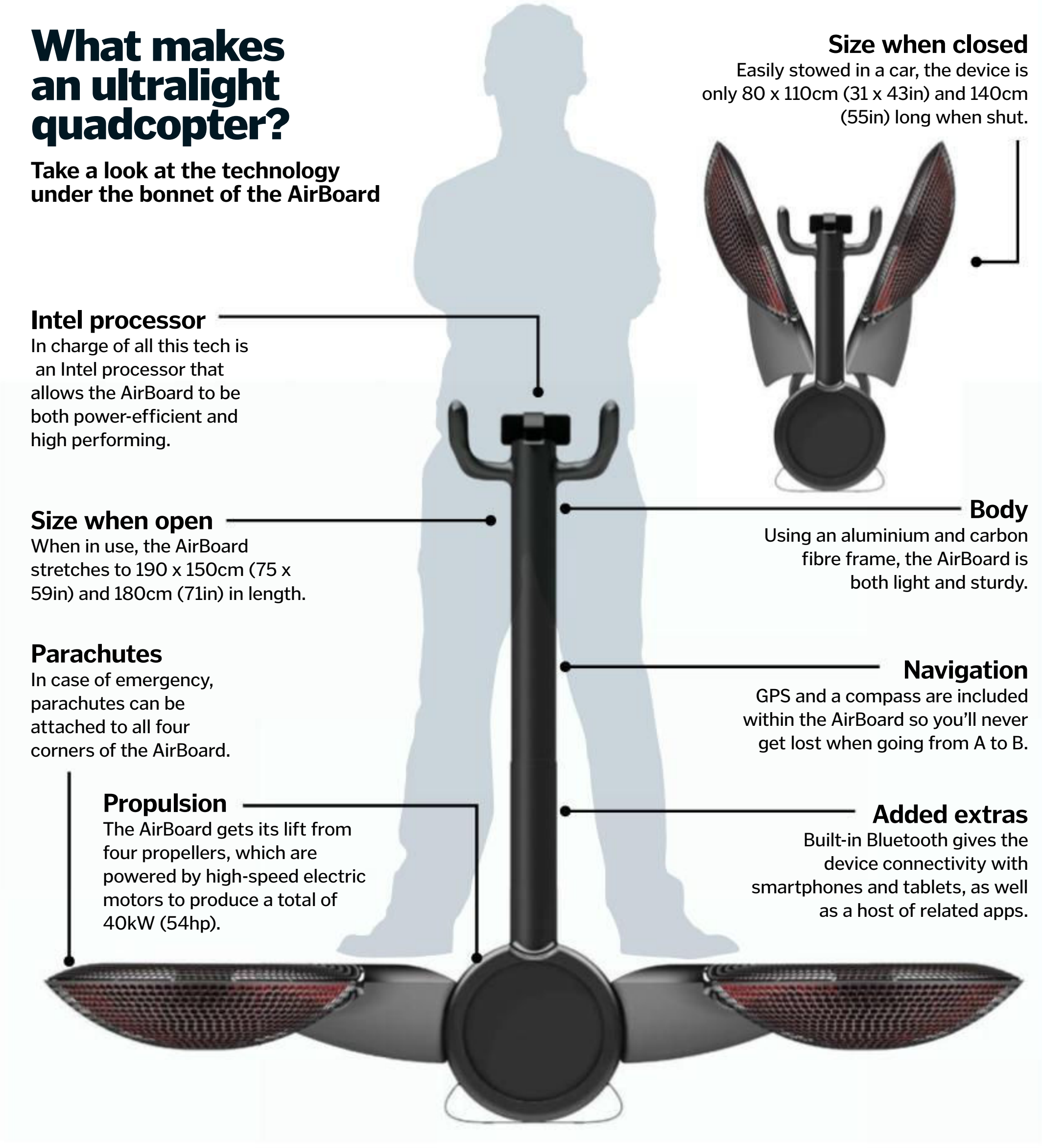
Ever wanted to fly but don't have the time or money to train as a pilot? The new AirBoard could be the answer. The smallest one-person aircraft in the world, it can carry the weight of a single person using its powerful battery. The AirBoard is classified as an ultralight quadcopter aircraft and it's small enough to fit in the boot of your car.

Its thrust is provided by four high-speed electric motors that each power a propeller. The drive system is managed by an Intel processor chip that incorporates a ground collision sensor to keep the board at a set height above the ground. This system comes into its own when you take the AirBoard into the great outdoors. Designed for both urban and rural use, the quadcopter will hover over nearly all ground, whether it's a snowy plain, water, rocky terrain or just in the street.

The device is easy to control, requiring the user to merely lean in the direction they want to go. For safety, the board's altitude is limited to a tame 1.5 metres (4.9 feet). The AirBoard's qualities make it ideal for recreational use but its features also make it potentially useful in search and rescue for the emergency services and perhaps even espionage for the military.

What makes an ultralight quadcopter?

Take a look at the technology under the bonnet of the AirBoard



Size when closed
Easily stowed in a car, the device is only 80 x 110cm (31 x 43in) and 140cm (55in) long when shut.

Intel processor
In charge of all this tech is an Intel processor that allows the AirBoard to be both power-efficient and high performing.

Size when open
When in use, the AirBoard stretches to 190 x 150cm (75 x 59in) and 180cm (71in) in length.

Body
Using an aluminium and carbon fibre frame, the AirBoard is both light and sturdy.

Parachutes
In case of emergency, parachutes can be attached to all four corners of the AirBoard.

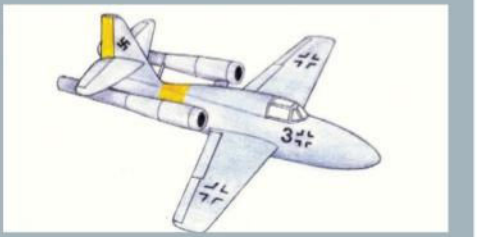
Navigation
GPS and a compass are included within the AirBoard so you'll never get lost when going from A to B.

Propulsion
The AirBoard gets its lift from four propellers, which are powered by high-speed electric motors to produce a total of 40kW (54hp).

Added extras
Built-in Bluetooth gives the device connectivity with smartphones and tablets, as well as a host of related apps.

The contenders

More tiny aircraft proving that bigger isn't always better



Messerschmitt Me-328
It may have never made it past the prototype stage, but the Messerschmitt Me-328 is the smallest pulsejet fighter of all time. It would have been used by Nazi Germany as a parasite fighter launched off larger aircraft.

Bumble Bee II
The tiny 2.7m (8.8ft)-long Bumble Bee II is listed by the *Guinness Book Of Records* as the smallest aircraft ever made, but it was sadly destroyed in a crash in 1988.

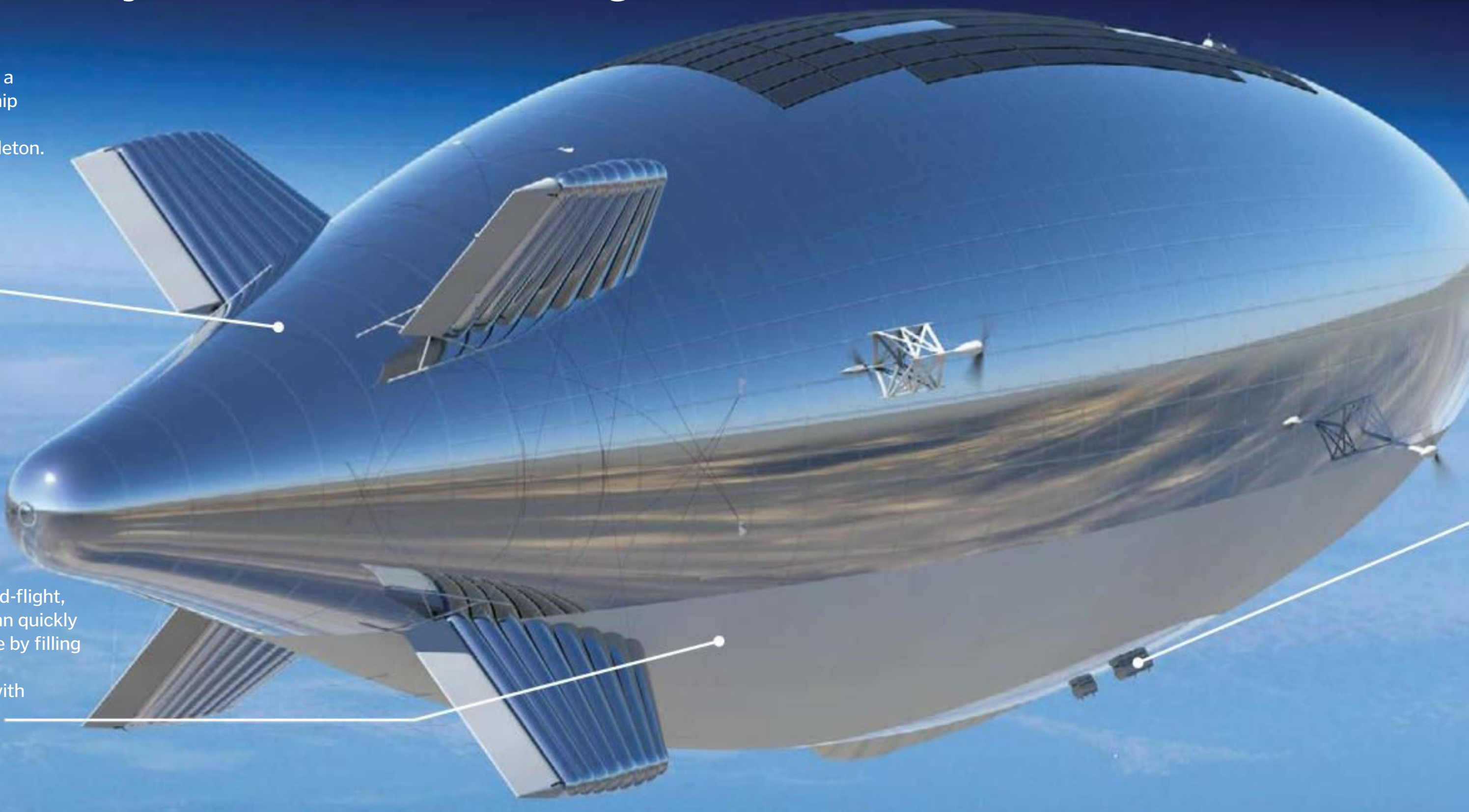
Bede Bd-5
The Bede BD-5 is considered the smallest civilian jet but not the world's smallest aircraft. Its first flight was in 1971 and despite its 3.8m (12.5ft) length it can reach a top speed of 483km/h (300mph).

XF-85
A prototype parasite fighter like the Me-328, the American XF-85 Goblin was the world's smallest jet fighter. At 2,050kg (4,519lb) when loaded, it is significantly heavier than the civilian aircraft on the list, mainly due to its four machine guns.

© AirBoard; Thinkstock

How next-gen airships work

Climb aboard these ultra-light giants for a journey into the future of flight



Hard body
The Aeroscraft is a rigid-bodied airship built around an internal steel skeleton.

No tipping
If cargo shifts mid-flight, the Aeroscraft can quickly regain its balance by filling counterbalanced compartments with compressed air.

It makes for a breathtaking image: a near-silent goliath of an airship hovering only a few thousand metres above the Grand Canyon or the Norwegian fjords. Inside the airship's roomy accommodations, 200 passengers enjoy their luxury air cruise, a slow but scenic tour of the world's most impressive landscapes.

This is the vision of a new generation of airship engineers and entrepreneurs who believe that dirigibles – rigid-bodied aircraft filled with helium – will be the efficient, eco-friendly transport of the future.

Dirigibles already have a long history. The first manned airship flights were made more than 120 years before the Wright brothers. In the 1780s, French innovators experimented with the first hot-air balloons and hydrogen-filled blimps. In the early days, hydrogen was the preferred gas for lighter-than-air vehicles because it is cheap, plentiful and the lightest substance on Earth – 14 times less dense than air. Unfortunately, it's also highly flammable.

By the early-20th century, German company Luftschiffbau Zeppelin was creating the world's largest and most powerful rigid-bodied dirigibles as both warships and passenger liners. The fiery crash of the hydrogen-filled Zeppelin Hindenburg in 1937, however, effectively burst the golden age of the airship.

Today's dirigibles, inflated with inert helium, fly more like aeroplanes than blimps. These 'hybrid' airships are powered by four or more jet engines that can fully rotate for both horizontal and vertical thrust. In vertical position, the engines are able to lift the airship straight off the ground, eliminating the need for runways. Once up in the air, the rigid, ellipsoid body of the airship also provides aerodynamic lift when cruising.

The combination of buoyancy (helium), vectored thrust (jet engines) and aerodynamic lift (body) results in far greater fuel efficiency than large planes or helicopters. For that reason, airships are being marketed as heavy lifters that can bring 50-500 tons of cargo to remote locations. In ten years, airship designers expect a 200-ton capacity airship to burn 0.1 kilograms (0.22 pounds) of fuel for every 1,000 kilograms (2,204 pounds) of cargo flown one kilometre (0.6 miles). Today, a

RECORD BREAKERS
AEROSCRAFT PAYLOAD

60,963kg

THE LIGHTWEIGHT HEAVYWEIGHT

Despite its delicate appearance, the Aeroscraft can actually lift the equivalent of 15 fully grown African elephants (close to 61,000 kilograms/134,400 pounds) in its cargo hold.

DID YOU KNOW? *The Hindenburg was designed to fly with helium, but German engineers were forced to retrofit for hydrogen*

> "Today's dirigibles, inflated with inert helium, fly more like aeroplanes rather than blimps"

Hover craft
The Aeroscraft's six powerful turbine engines allow it to hover in place while carrying a full payload, even loading and unloading cargo.

100-ton capacity 747 jumbo jet burns three times that amount.

A big player in the airship renaissance is the military. The US Army has invested billions in airships as surveillance aircraft and troop movers. Unmanned airships can hover for three weeks at a safe altitude of 6,000 metres (20,000 feet) over targets and airship personnel carriers can take off and land from desert, ice or water.

Within the next 20 years, airship engineers expect to witness a transportation revolution. Green airships will carry drilling rigs to the Arctic Circle. A flotilla of dirigibles will take troops and tanks into warzones. And you and your family may be going on 'sky cruises' on holidays with a whole new perspective.

The statistics...

Aeroscraft

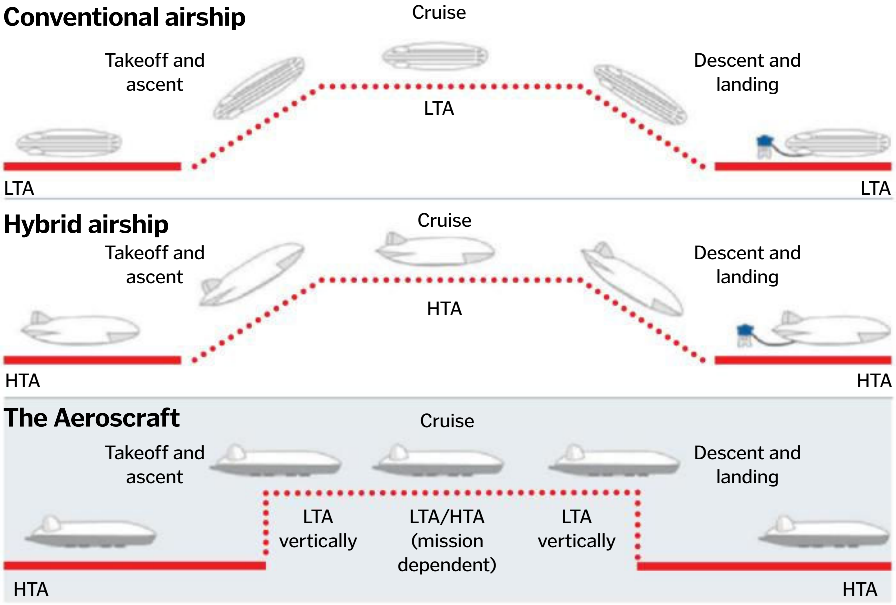
Length:	152m (500ft)
Span:	49m (160ft)
Total passengers:	180
Range:	5,744km (3,569mi)
Cruise speed:	222km/h (138mph)
Altitude:	3,658m (12,000ft)

Introducing the Aeroscraft

Measuring 152 metres (500 feet) long, luxury liner Aeroscraft will hold 180 passengers as they cruise at 222 kilometres (138 miles) per hour. Travellers can admire the view afforded by floor-to-ceiling windows as the floating giant hovers 3,658 metres (12,000 feet) over the Earth. Aeros describes it as the only next-gen airship capable of truly vertical takeoff and landing; even hybrid airships need a running start to achieve lift. On the Aeroscraft, rapid ascent is powered by a combination of the ship's store of helium and six turbofan jet engines. The difference between Aeroscraft and other airships is an internal ballast system called Dynamic Buoyancy Management. When an airship loads or unloads cargo, the change in weight must be counterbalanced by adding or removing ballast else the vehicle will be too heavy to fly or too light to navigate. Instead of loading and unloading water ballast during takeoff and landing, the Aeroscraft can adjust internal buoyancy by taking in air from the outside and compressing it in internal compartments.

How does Aeroscraft take to the skies?

Compare the Aeroscraft's takeoff and landing abilities with other airships

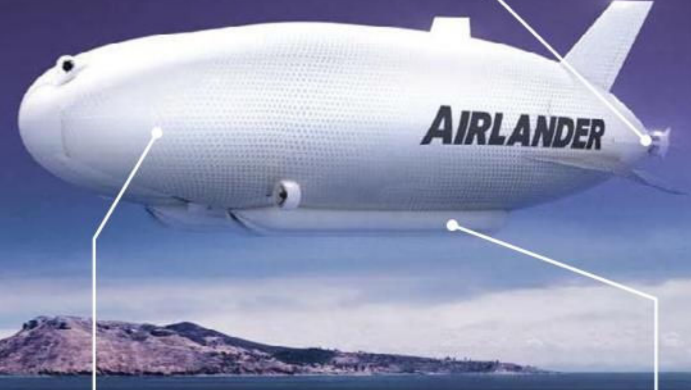


LTA = Lighter than air HTA = Heavier than air

It's estimated that the Aeroscraft will be able to cross the USA in around 18 hours

Meet the Airlander

The 90-metre (295-foot) Airlander, manufactured by Hybrid Air Vehicles, is a 'hybrid' aircraft with the vertical takeoff agility of a helicopter and the long-range flight capabilities of a conventional airship. Only 40 per cent of the Airlander's lift is supplied by helium. The rest is powered by four turbine engines. This extra muscle enables the football field-sized Airlander to carry payloads of up to 200 tons. The Airlander comes in two models: one for heavy-lift transportation and another for military use. When fully loaded with six 6.1-metre (20-foot) shipping containers, the Airlander can travel 2,500 kilometres (1,600 miles) at a top speed of 160 kilometres (100 miles) per hour. With its vertical takeoff and landing capabilities, the Airlander doesn't require a runway and can land on any reasonably flat surface, including water, snow, ice and sand. The US Army has purchased a fleet of Airlanders for long-range surveillance, both manned and unmanned. On an unmanned surveillance mission, the Airlander can hover above a target zone and provide what the military calls an 'unblinking stare' for 21 days straight without refuelling. The Airlander is marketed as a 'green' transport solution, using far less fuel than conventional aircraft, and supplying a point-to-point solution that eliminates environmentally invasive infrastructure like major roads and airstrips.



Cheap flight
The unmanned surveillance version of the Airlander can fly for weeks on 8,000kg (18,000lb) of fuel costing just £12,600 ($20,000).

Not a blimp
The envelope of the Airlander isn't a blimp-like balloon, but a rigid body formed from a blend of Kevlar, Mylar and Vectran.

ACLS
The air cushion landing system deploys an inflatable cushion to soften landings and provide suction to hold the craft still during loading and unloading.

The statistics...

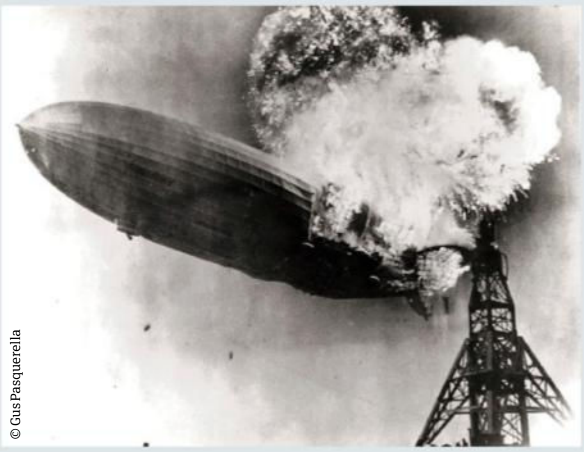
Airlander

Length: 90m (295ft)
Cruise speed: 148km/h (92mph)
Max altitude: 6,096m (20,000ft)
Max payload: 200,000kg (440,925lb)
Endurance: 21 days (unmanned)
Power: 7,457kW (10,000shp)

Airships like the Airlander will be able to land in terrain that most other aircraft would struggle with

The Hindenburg disaster

The newsreel footage is as powerful today as it must have been on 6 May 1937, when announcer Herbert Morrison choked with emotion as he described the explosive consumption and crash of the LZ-129 Hindenburg, one of the largest (and the last) airships of the era. The exact cause of the fire is unknown – engine backfire, lightning, even sabotage – but the explosion was fuelled by the highly flammable hydrogen gas used to keep the 245-metre (803-foot) dirigible afloat. Incredibly, only 35 people died of the 97 on board.



© Gus Pasquerella

DID YOU KNOW? In 1785, Jean-Pierre Blanchard crossed the English Channel in an airship propelled by flapping wings

Enter the SkyTug

Lockheed Martin was one of the top competitors when the US Army went shopping for a new surveillance aircraft. In 2006, the Army passed on Lockheed's next-generation P-791 hybrid airship in favour of the Airlander, a similar aircraft built by Britain's Hybrid Air Vehicles and American defence contractor Northrop Grumman. Now the P-791 has been revived as the SkyTug, a hybrid airship poised to serve oil and gas rigs drilling in remote locations. The SkyTug works almost exactly like the Airlander, achieving lift through a combination of helium and fully rotating turbine engines. A Canadian firm recently ordered a SkyTug with a 20-ton cargo capacity, but Lockheed says the design is scalable to handle five times that weight. The SkyTug's air cushion landing system features inflatable landing surfaces that enable the airship to land on almost any terrain, much like its competitor the Airlander. Lockheed is billing the SkyTug as the perfect long-range transport for heavy machinery and equipment. Instead of building expensive roads or railways to Arctic drilling sites, we can now ship heavy equipment via airship. To this end, hybrid airships like the SkyTug can operate in temperatures as low as -56 degrees Celsius (-68 degrees Fahrenheit).

The statistics...

SkyTug

Length: 76.2m (250ft)

Max speed: 148km/h (92mph)

Max altitude: 6,096m (20,000ft)

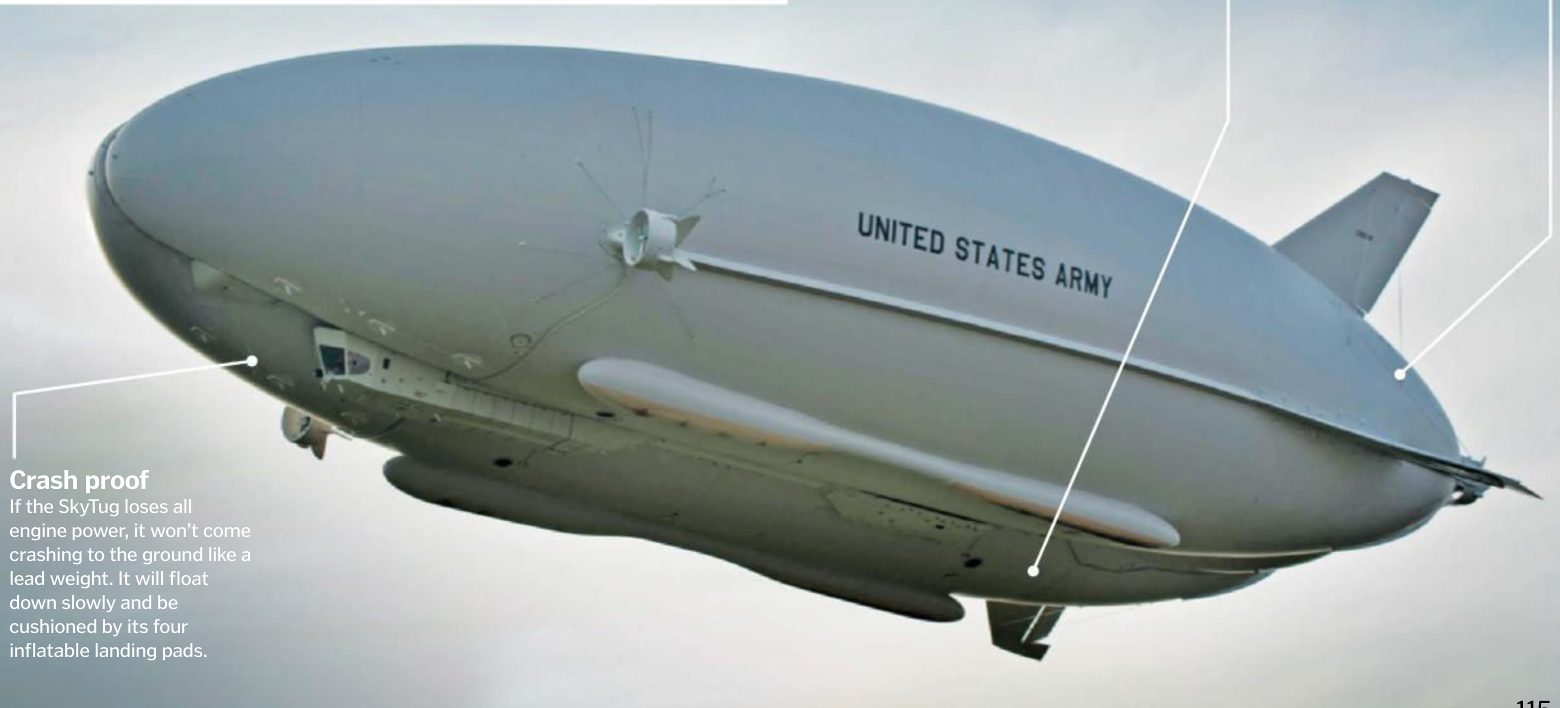
Endurance: 21 days

Payload: From 20,000kg (44,092lb)

Min temperature: -56˚C (-68˚F)

© Aeros; Hybrid Air Vehicles; Lockheed Martin

The SkyTug was originally intended to be used by the US Army but lost out to the Airlander



Suction
The SkyTug doesn't need to be tied down to a mooring station after landing. The landing system doubles as suction, gripping the ground even in high winds.

Floating freight
Lockheed hopes to launch an entire new industry with the SkyTug: point-to-point shipping of heavy machinery by airship.

Crash proof
If the SkyTug loses all engine power, it won't come crashing to the ground like a lead weight. It will float down slowly and be cushioned by its four inflatable landing pads.

Spacecraft

118 **Exploring the outer Solar System**
Meet the handful of spacecraft that have ventured to the furthest reaches of space

122 **The evolution of space travel**
Take a look at ten important space missions

124 **The Orion spacecraft**
How the replacement for NASA's Space Shuttle will take us to the Moon and beyond

126 **On board the SpaceShipTwo**
Will this kickstart commercial flights into space?

128 **Voyager spacecraft**
What path have the Voyager probes taken and where are they now?

130 **The MESSENGER probe**
Discover the first spacecraft to make the voyage to and explore Mercury since 1975

132 **Big Space Balloon**
How will this giant stratospheric balloon reach the edge of space?

134 **Space Shuttle payload bay**
Discover how this colossal craft delivers tons of supplies and tech into space

136 **Automated transfer vehicles (ATVs)**
Keeping the International Space Station fully stocked with the help of ATVs

138 **Solar-powered spacecraft**
Harnessing energy from the Sun, solar-powered probes are environmentally friendly

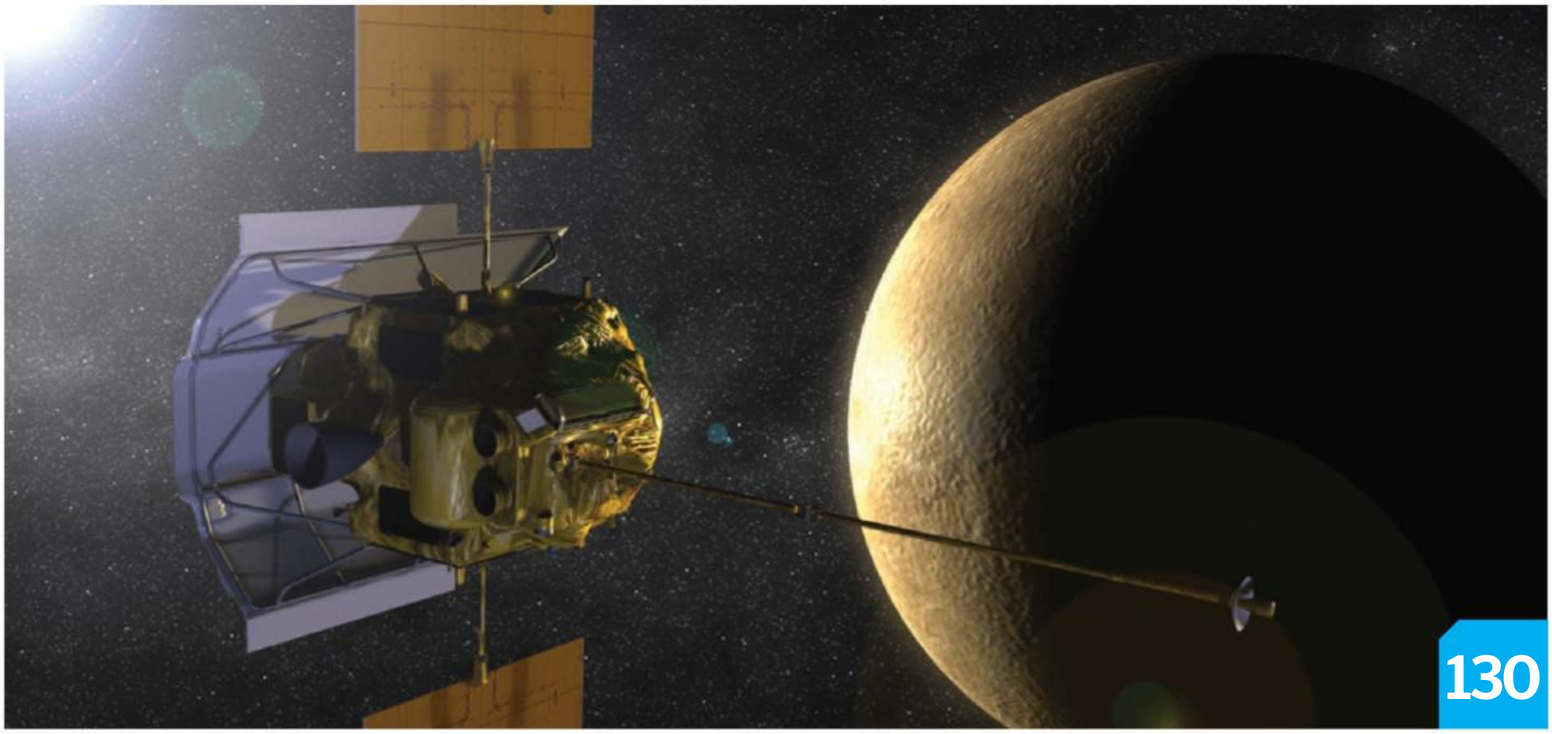
140 **Next-gen space planes**
How the next generation of aircraft will help us venture into space like never before

"In five decades, space travel has truly come on leaps and bounds"

128

118

126



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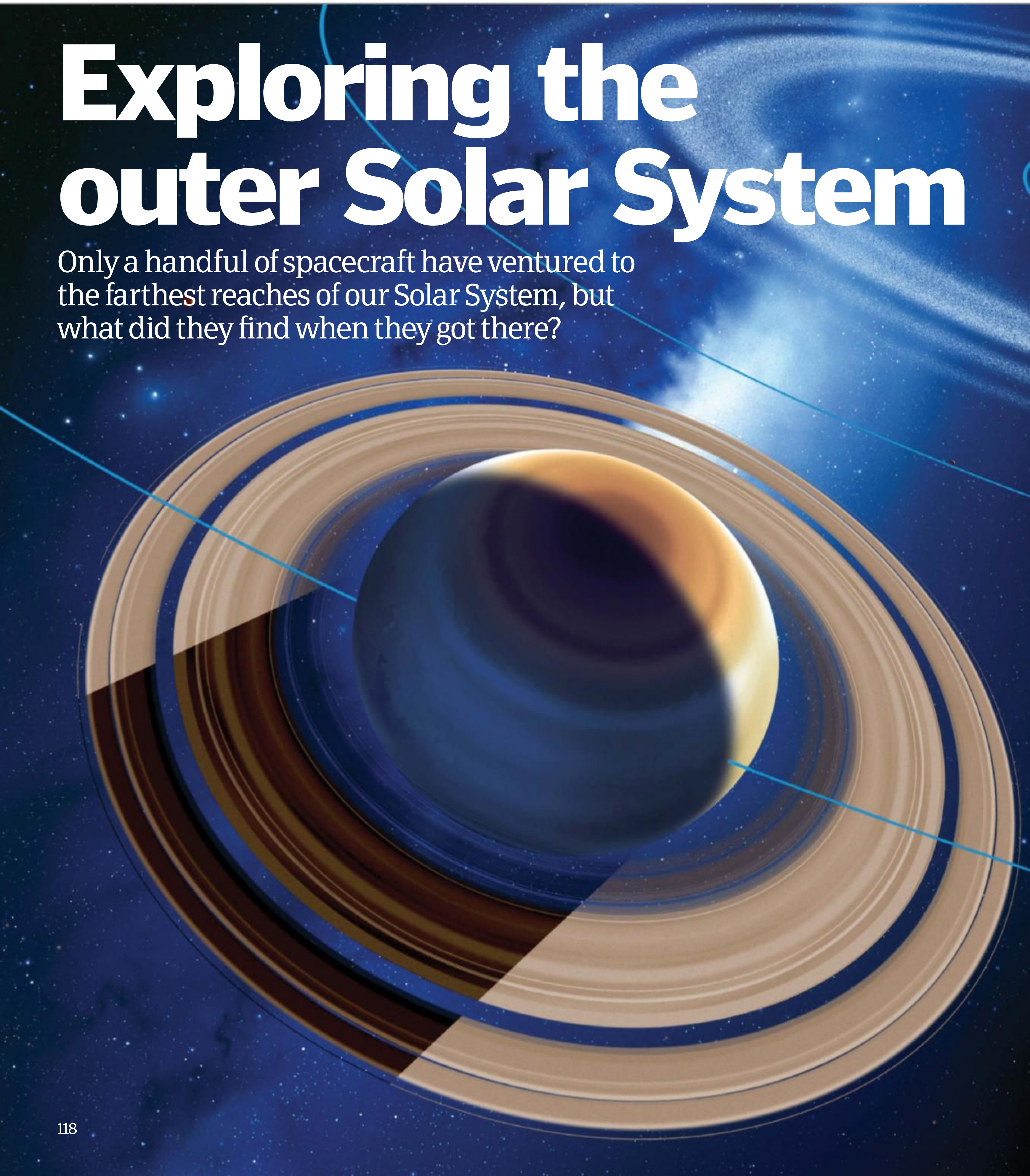
Exploring the outer Solar System

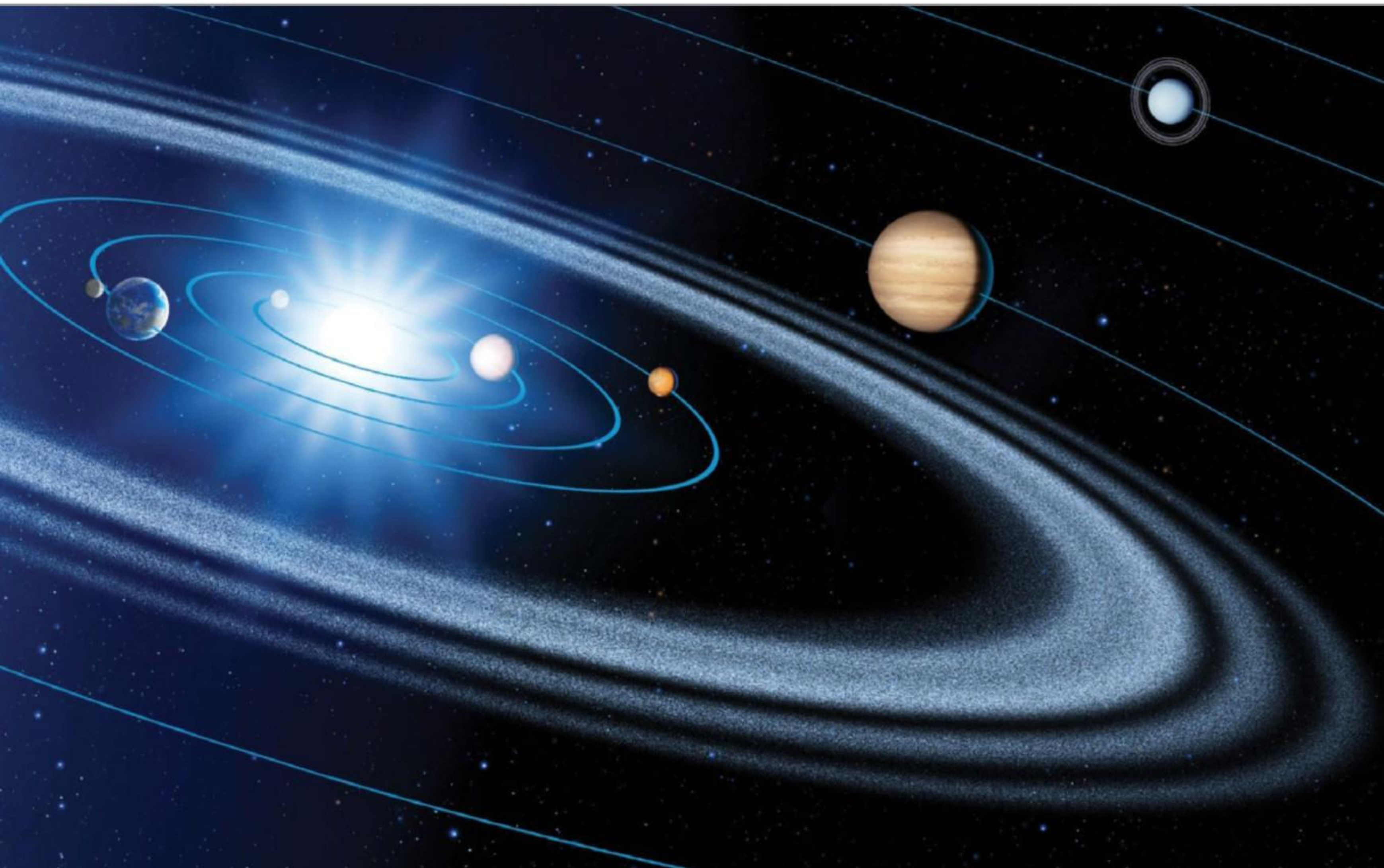
Only a handful of spacecraft have ventured to the farthest reaches of our Solar System, but what did they find when they got there?



THE STATS
CASSINI MISSION

MISSION COST $3.27bn
PHOTOS TAKEN TO DATE 300,000
NAMED SATURNIAN MOONS PASSED 53
YEAR OF TITAN'S DISCOVERY 1655
LENGTH OF CASSINI'S WIRES 12km
DATA CAPTURED 300GB

DID YOU KNOW? *It takes almost 90 minutes for radio signals from Saturn to reach us on Earth*



On 14 January 2005, the world got its first proper look of Titan. A spray of yellow stones on a sandy backdrop extending into a hazy sky, it could easily have been mistaken for a sepia-toned photograph from a desert, taken back in the Sixties. It's not what most people would expect a land of liquid methane lakes, water-ice rocks and an average daytime temperature of -179 degrees Celsius (-290 degrees Fahrenheit) to look like.

This was our first closeup of anything in the outer Solar System, however. Previously we had nothing but giant telescopes or passing probes taking photos of the four planets and their many moons but often from millions of miles away. The ESA's Huygens probe, piggybacking NASA's Cassini spacecraft, had plunged through Titan's dense nitrogen and methane clouds that had veiled its surface from our prying eyes ever since its discovery, down to the rocky ground below. Because its relay, Cassini, was moving out of range at the rate of five metres (16 feet) a second, Huygens was only designed for 30 minutes of data acquisition in mind, even though it continued to transmit data for just over an hour and a half.

Though Cassini is revealing unprecedented detail about Saturn, we're still scraping the surface of what we can learn about this gas giant – and there's still a black hole of knowledge to be filled in about the outer Solar System in general. We've managed to visit Mars, Venus and the planets on our galactic doorstep within the Asteroid Belt with all manner of spacecraft, but our cosmic 'backyard' is still wild and unexplored. Historically, the farther beyond Mars we look, the fewer probes we see making the huge journey to the strange celestial bodies that dwell far from the warmth of the Sun. Jupiter has had six successful flybys by separate spacecraft and one orbiter (Galileo) while Saturn has had three flybys and one orbiter (Cassini). Uranus and Neptune have only ever had a fleeting visit by the Voyager 2 probe, while dwarf planet Pluto (about 5.9 billion kilometres/3.7 billion miles from the Sun) is yet to get its own closeup, but New Horizons is set to reach it in 2015.

Saturn being the current planet on NASA's 'Grand Tour' of the outer planets, Cassini is getting a lot of attention at the moment. Its primary mission was to study Saturn and its satellites in close proximity, but in the seven-year journey to the sixth planet from the Sun, it collected a staggering amount of data simply flying past planets it was using to carry out a gravitational assist. Venus, Earth and the Moon got a slew of calibration shots to add to their portfolios as their gravity was used to propel Cassini towards Saturn. Jupiter was analysed in greater detail, photographed 26,000

© SPL

> *"Pioneer 11 is on a course that will see it pass one of the stars in the Aquila constellation in 4 million years' time"*

times in Cassini's six-month Jovian flyby. It added to the bounty of information gathered by the Galileo orbiter in its eight-year mission that concluded in 2003, along with the Galileo probe that sacrificed itself in the name of astronomy by plummeting into the vice-like pressures beneath Jupiter's gaseous surface.

Although all contact has now been lost with the Pioneer 10 spacecraft that launched in 1972, its mission to fly by Jupiter was a success at a time when landing on the Moon was still fresh in everyone's mind. It took 500 photos of the behemoth before moving on to the chilly outer fringes of our Solar System, gathering data until its power failed in 2003 at a distance of 12 billion kilometres (7.5 billion miles) from Earth.

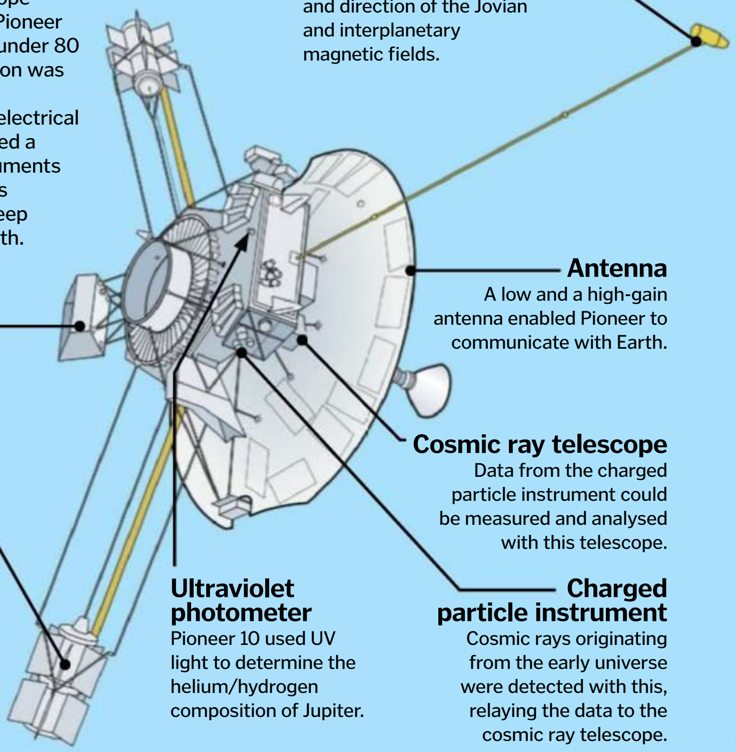
Pioneer 11, which has performed flybys of both Jupiter and Saturn, has suffered from similar technical issues (in this case with its radio) and is lost in the outer Solar System on an extrasolar course that will see it pass one of the stars in the Aquila constellation in around 4 million years' time. Similarly, Voyager 2 is bordering on the farthest reaches of the Sun's influence, having flown by Jupiter, Saturn, Uranus and Neptune in the Seventies and Eighties. In contrast, both Voyager 1 and 2 are, amazingly, still fully functional and in regular communication with NASA headquarters.

Cassini entered Saturn's orbit on 30 June 2004, seven years after its launch. The next four years of its initial mission it spent scanning Saturn's surface, its rings and its moons to gain an unprecedented understanding of the Saturnian system. Its primary objective was completed in 2008 and, with nearly a decade of life left in Cassini, NASA embarked on the two-year extended Equinox mission in which the craft orbited Saturn another 60 times with 36 flybys of its moons, including 26 close encounters with Titan. Cassini's current extended mission – Solstice – began on 12 October 2010 and will end in 2017, just in time for the summer solstice of Saturn's 29-year orbit in its northern hemisphere.

Probably the most famous of all probes, though, is Voyager 1. It actually launched a month after Voyager 2 but because of Voyager 2's more convoluted trajectory, it passed its older sibling as the farthest man-made object from Earth and is on track to be the first man-made object to exit the Solar System into interstellar space. On its path to extrasolar glory, it has examined Jupiter, Saturn and its biggest moon Titan, providing the first detailed images of all three of these celestial bodies.

Pioneer 10's technology

Powered by a lump of plutonium-238 isotope inside four radioisotope thermoelectric generators, Pioneer 10 should have been at just under 80 per cent when communication was lost in 2003, due to rapid deterioration of several key electrical points on the craft. It powered a load-out that included instruments for gathering and sometimes processing raw data from deep space to be sent back to Earth.



Magnetometer
Held out by a boom arm, this measured the strength and direction of the Jovian and interplanetary magnetic fields.

Asteroid-meteoroid detector sensor
Always on the hunt for interesting objects, Pioneer 10 could track anything from motes of dust to passing asteroids.

Antenna
A low and a high-gain antenna enabled Pioneer to communicate with Earth.

Cosmic ray telescope
Data from the charged particle instrument could be measured and analysed with this telescope.

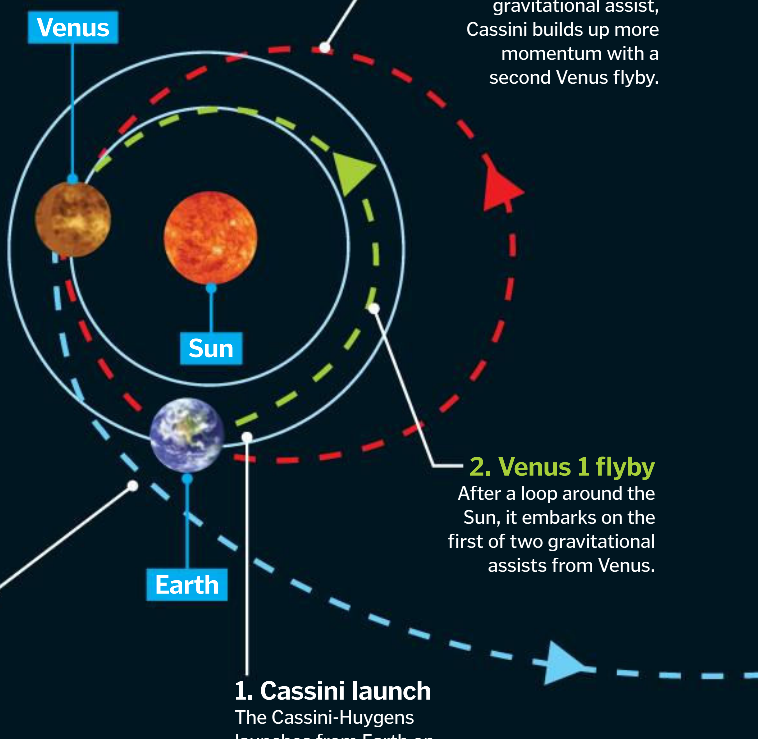
MMRTGs
Pioneer 10 used multi-mission radioisotope thermoelectric generators to power its systems. Each of the four MMRTGs harnessed heat from 4.8kg (10.6lb) of plutonium-238 to produce electricity and could be used in both an atmosphere or a vacuum.

Ultraviolet photometer
Pioneer 10 used UV light to determine the helium/hydrogen composition of Jupiter.

Charged particle instrument
Cosmic rays originating from the early universe were detected with this, relaying the data to the cosmic ray telescope.

What are gravitational assists?

Sending a probe directly to the outer planets by pointing the spacecraft in the right direction and blasting away can cost a prohibitive amount of fuel. Instead, using well-found techniques, NASA can calculate a trajectory that uses the gravity of the inner planets to 'slingshot' the craft in an increasingly wider orbit. With this added velocity, they are able to shoot off on course for a journey beyond the Asteroid Belt. In this diagram, we reveal how the Cassini-Huygens craft used gravity assists to get to Saturn…



3. Venus 2 flyby
Over a year after its first gravitational assist, Cassini builds up more momentum with a second Venus flyby.

2. Venus 1 flyby
After a loop around the Sun, it embarks on the first of two gravitational assists from Venus.

4. Earth flyby
The probe bids farewell to its home world as Earth gives it the momentum it needs to leave the inner Solar System.

1. Cassini launch
The Cassini-Huygens launches from Earth on the back of a Titan IVB/Centaur booster.

HEAD 2 HEAD
SATURNIAN MOONS

1. BRIGHTEST

Enceladus
This cold moon (-201 degrees Celsius/-330 degrees Fahrenheit) is covered in water-ice, reflecting nearly 100 per cent of sunlight.

2. WEIRDEST

Iapetus
Even NASA thinks that this moon is odd. One side is jet-black and the other white; and while it looks like it should have a 16-hour day, in fact it's 79 Earth days long!

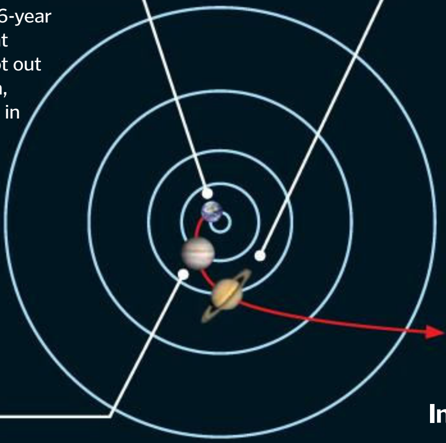
3. SPONGIEST

Hyperion
This oddly shaped moon is the largest irregular-shaped satellite ever to be observed in space. Its pockmarked surface lends it a spongy appearance.

DID YOU KNOW? *One of Cassini's cameras is so sensitive that it can take clear pictures of a coin 4km (2.5mi) away!*

Voyagers' journey to the edge of the Solar System

Compare the routes of Voyager 1 and Voyager 2 and discover how they have managed to get so far…

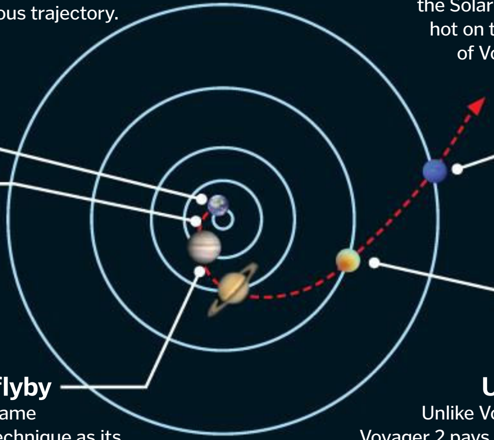


Voyager 1 launch
Exploiting a rare 176-year planetary alignment window to slingshot out of the Solar System, Voyager 1 launches in September 1977.

Saturn flyby
Over a year after the Jupiter encounter and Voyager 1 uses the gravity of Saturn to propel itself on.

Jupiter flyby
Voyager 1 says a brief hello to Jupiter in March 1979.

Interstellar space
Voyager 1 is propelled onward on a trajectory that will take it directly out of the Solar System.



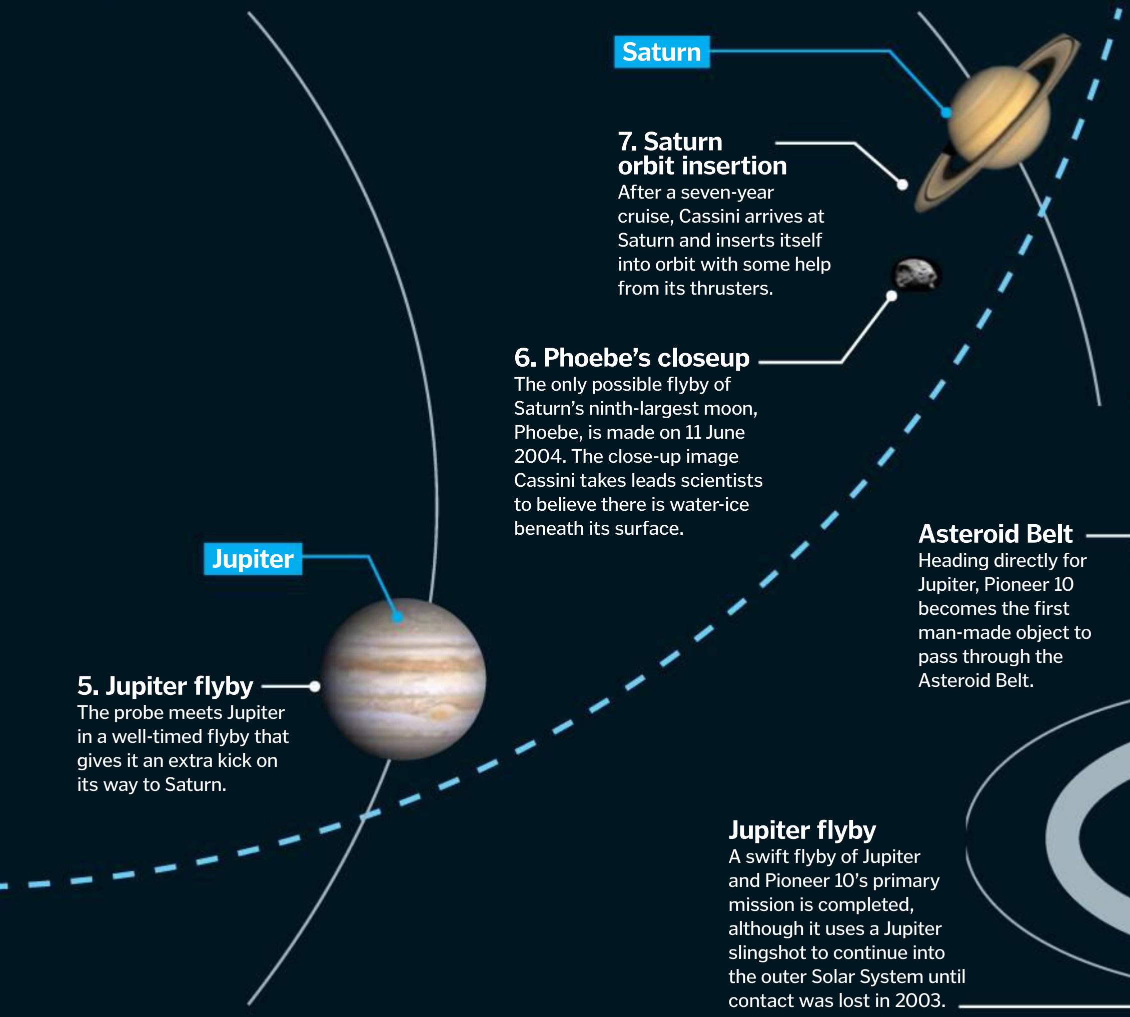
Voyager 2 launch
Voyager 2 launches the month before Voyager 1 but on a longer, more circuitous trajectory.

Spacecraft overtake
Voyager 2 is overtaken as Voyager 1 takes a more direct route onward.

Jupiter flyby
Using the same slingshot technique as its sibling, Voyager 2 takes advantage of Jupiter's gravity to push itself on.

Neptune
Its final, fleeting visit is to Neptune before Voyager 2 makes its way out of the Solar System, hot on the heels of Voyager 1.

Uranus
Unlike Voyager 1, Voyager 2 pays a visit to Uranus having swung around Saturn for another assist.



7. Saturn orbit insertion
After a seven-year cruise, Cassini arrives at Saturn and inserts itself into orbit with some help from its thrusters.

6. Phoebe's closeup
The only possible flyby of Saturn's ninth-largest moon, Phoebe, is made on 11 June 2004. The close-up image Cassini takes leads scientists to believe there is water-ice beneath its surface.

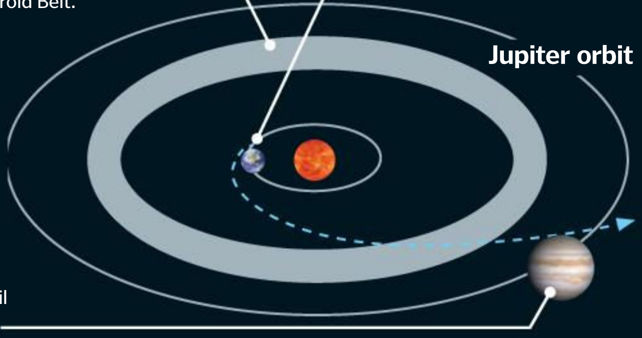
5. Jupiter flyby
The probe meets Jupiter in a well-timed flyby that gives it an extra kick on its way to Saturn.

Testing Einstein

One of the tasks Voyager performed was to put Einstein's theory of general relativity to the test – specifically the curvature of space-time. The idea is that a massive body like the Sun would increase the distance radio waves have to travel as its gravity greatly distorts space-time. Radio waves were beamed from Voyager to Earth and back, resulting in a measured frequency shift as the radio waves passed by the Sun. The experiment has also been performed by the Mars Viking programme and Cassini, and all three experiments produced the same results – totally supporting Einstein's theory.

Pioneer 10's route

Where has this probe travelled since it launched and what has it seen?



Asteroid Belt
Heading directly for Jupiter, Pioneer 10 becomes the first man-made object to pass through the Asteroid Belt.

Moon
11 hours after launch, Pioneer 10 reaches the Moon.

Jupiter flyby
A swift flyby of Jupiter and Pioneer 10's primary mission is completed, although it uses a Jupiter slingshot to continue into the outer Solar System until contact was lost in 2003.

© NASA

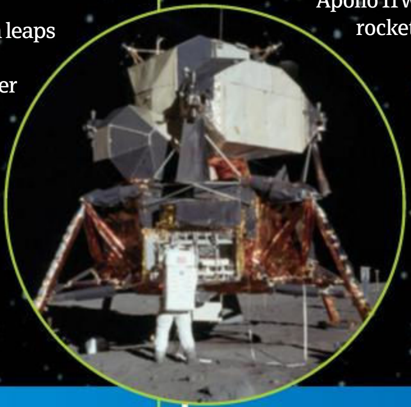
> *"Japan's Hayabusa probe was the first spacecraft to return a sample from an asteroid"*

SPACE TRAVEL

We take a look at ten important space missions and the craft that undertook them

Since Russia's Sputnik 1 satellite entered space on 4 October 1957, thousands of spacecraft, including Earth satellites and deep-space probes, have launched into the cosmos.

In those five decades space travel has truly come on leaps and bounds, with the development of liquid and solid fuels, and the use of solar panels and radioactive power sources among many of the impressive innovations, allowing space agencies across the planet to undertake evermore ambitious missions that would once have never been thought possible. Here, **How It Works** has compiled ten of the most successful missions that have advanced the field of space travel to a whole new level.



1969

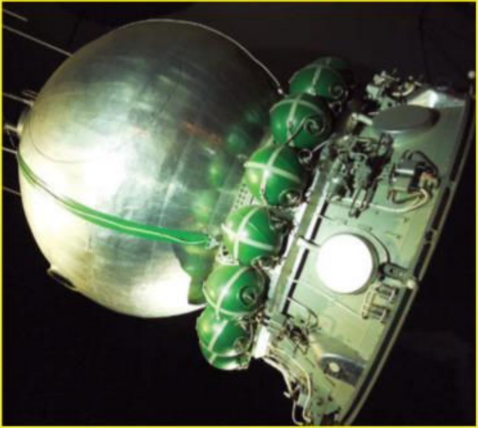
Apollo 11

Probably the most well-known space mission of all time, Apollo 11 was launched atop the most powerful rocket to date, the Saturn V. The spacecraft was composed of two sections – the Lunar Module and the Command Module – the latter of which remained in orbit around the moon with Michael Collins on board while the former took astronauts Neil Armstrong and Buzz Aldrin to the surface. Apollo 11 paved the way for a further five successful missions to the moon, each spending several days on the lunar surface.

1960s

1970s

1980s



1961

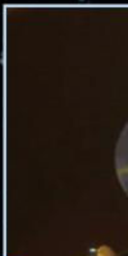
Vostok 1

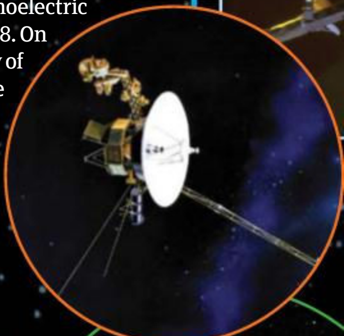
In 1961 Yuri Gagarin became the first man to travel to space, and the spacecraft that took him there for 68 minutes, was a fairly rudimentary sphere known as Vostok 1. As this was the first manned craft to leave Earth orbit, lots of extra precautions were taken, eg Gagarin was not able to freely move around the cabin, nor was he able to manually control the spacecraft. Nonetheless, in the timeline of space exploration, Vostok 1 is without a doubt one of the most important spacecraft of all time.

1961-1984

Venera probes

The Venera missions have been Russia's most successful space exploration missions to date. In total, 23 separate probes were launched to the hottest planet in our solar system, Venus, between 1961 and 1984, with ten of these landing on the surface. Each Venera lander was a technical marvel, withstanding incredible temperatures of up to 462 degrees Celsius (864 degrees Fahrenheit) to remain operational for up to two hours. They returned key data about the surface of Venus, including detailed information on the planet's atmospheric structure.

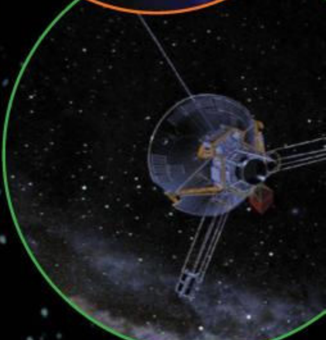




1977-present

Voyager 1 and 2

The Voyager programme was originally designed to explore Jupiter, Saturn, Uranus and Neptune, but the mission was extended to include the boundary into interstellar space, which they are currently entering. The Voyager probes both receive power from three radioisotope thermoelectric generators, fed by plutonium-238. On board each probe is a variety of sounds and images known as the Golden Record, which also contains instructions on how to find Earth for any passing aliens.

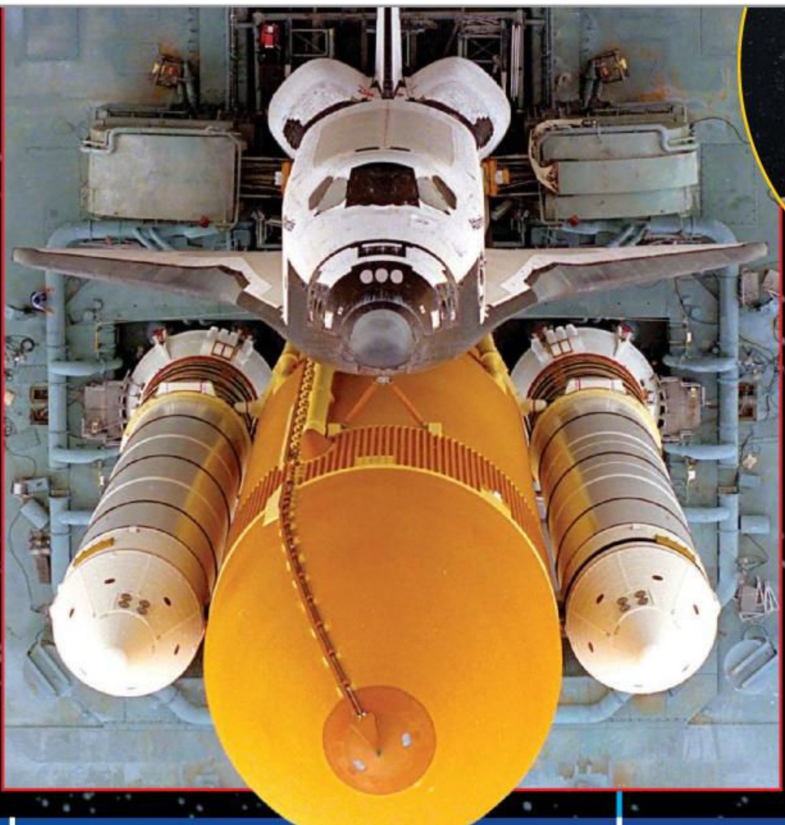


1972-2003

Pioneer 10 and 11

The purpose of the Pioneer missions was to learn about the outer reaches of the solar system. These two spacecraft were, at the time of their launch, the most advanced vehicles to venture into space. They contained a number of technical tools never used before, including a charged particle instrument to measure the extent of the Sun's influence. While comms were lost in 1995 (Pioneer 11) and 2003 (Pioneer 10), the probes continue to make their way out of the solar system, with each possessing an on-board plaque detailing their origins.

DID YOU KNOW? *Voyager 1 was the first spacecraft to enter interstellar space on 25th August, 2012*



1981-2011

Space Shuttles

NASA's five cosmos-faring Space Shuttles were the largest spacecraft of all time, and each completed numerous missions that defined them as some of the most important vehicles to enter Earth orbit. Their many accolades include taking the Hubble Space Telescope into orbit (and later repairing it) and launching more than 80 per cent of the modules for the ISS. There were 135 missions in total, but two of these ended in tragedy. The Challenger spacecraft exploded 73 seconds after launch in 1986, while in 2003 the Columbia spacecraft was torn apart on re-entry. While the Shuttles are remembered largely as a success, these two disasters serve as a reminder of just how dangerous space travel is.

2003-2010

Hayabusa

Japan's Hayabusa probe was the first spacecraft to return a sample from an asteroid, but it wasn't without its problems. A fuel leak rendered its chemical engines unusable and, coupled with a variety of mechanical failures, the probe was forced to limp home on its weaker ion engines. It eventually arrived three years behind schedule in 2010, but the mission was still a success. Ion engines on spacecraft have become more and more popular due to their longevity, rather than relying on an initial big 'push'.

1990s

2000s

1989-2003

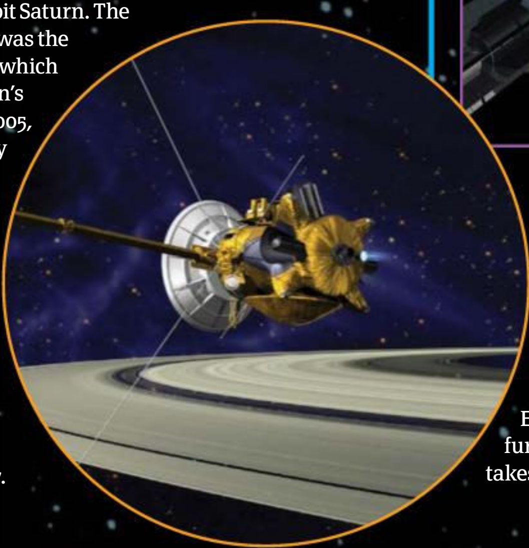
Galileo probe/ spacecraft

NASA's Galileo spacecraft was taken into space in 1989 and went on to study Jupiter after flybys of Venus and Earth. It was the first spacecraft to orbit Jupiter, in addition to performing the first flyby of an asteroid. It also carried the Galileo Space Probe, which it released into Jupiter's atmosphere in 1995, providing unprecedented data about the gas giant. In 2003 the orbiting spacecraft was sent crashing into our solar system's biggest planet to prevent it colliding with a nearby moon and causing contamination.

1997-present

Cassini-Huygens

The Cassini-Huygens probe was a joint mission between NASA, the ESA and ASI (Italian Space Agency) and is often regarded as the most successful deep-space probe of all time. The orbiting component of the probe flew by Jupiter and became the first spacecraft to orbit Saturn. The landing vehicle was the Huygens Probe, which landed on Saturn's moon Titan in 2005, the first and only successful landing in the outer solar system. As with most probes, it is powered by plutonium-238, which has enabled its mission to be extended to 2017.



2006-present

New Horizons

NASA's New Horizons spacecraft will become the first probe to fly by Pluto in 2015. While its primary mission is to study the (now) dwarf planet, it has also studied Jupiter and its moons. New Horizons is the fastest probe to have left Earth's orbit. It is currently more than 21 times further from the Sun than Earth; at that distance it takes almost three hours to send or receive a signal.

© NASA/JAXA/JPL/Caltech/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute/Pline

Space Shuttle's successor

The Orion spacecraft

How the replacement for NASA's Space Shuttle will take us to the moon and beyond

The primary goals of the Orion spacecraft, which has been contracted to technology company Lockheed Martin by NASA, are to deliver crew and cargo to the International Space Shuttle and return astronauts to the moon after almost a 50-year wait. Orion made its first test flight in December 2014 and is scheduled to complete a lunar mission by the early 2020s.

The Orion crew module is similar in design and appearance to the Apollo Command Module that first took astronauts to the moon. It is three times the volume of the Apollo module with the same 70° sloped top, deemed to be the safest and most reliable shape for re-entering Earth's atmosphere at high velocity. The Orion module has a diameter of five metres and a total mass of about 9,000kg including the cargo and the crew, which increases or decreases slightly for missions to the International Space Station and the moon respectively. Unlike the Apollo module, which had a crew capacity of three people, the Orion module can carry between four and six astronauts.

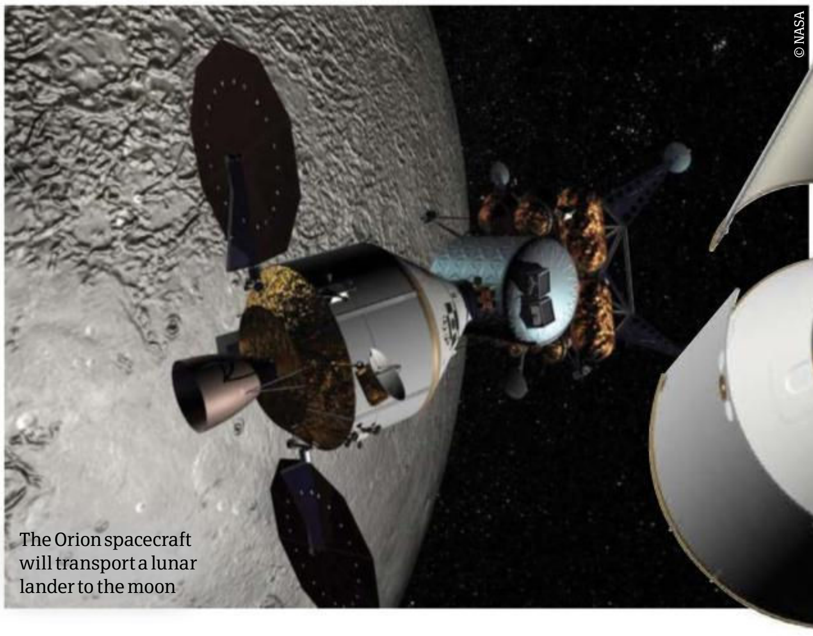
Attached to the crew module is the service module, responsible for propulsion, electrical power, communications and water/air storage. The service module is equipped with a pair of extendable solar panels that are deployed post-launch in addition to batteries to store power for times of darkness. Like the Orion crew module, the service module is also five metres in diameter to provide a clean fit between the two, and has a mass of about 3,700kg in addition to 8,300kg of propellant.

Exerting 33,000 newtons (7,500 pounds) of thrust, the engine of the service module uses hypergolic fuels monomethyl hydrazine and nitrogen tetroxide, which are propellants that ignite on contact with each other and require no ignition source. Another benefit of these propellants is that they do not need to be cooled like other fuels; they can be stored at room temperature. 24 thrusters around the service module will also give it control to change its orientation in all directions, but these are almost 30 times weaker than the main booster.

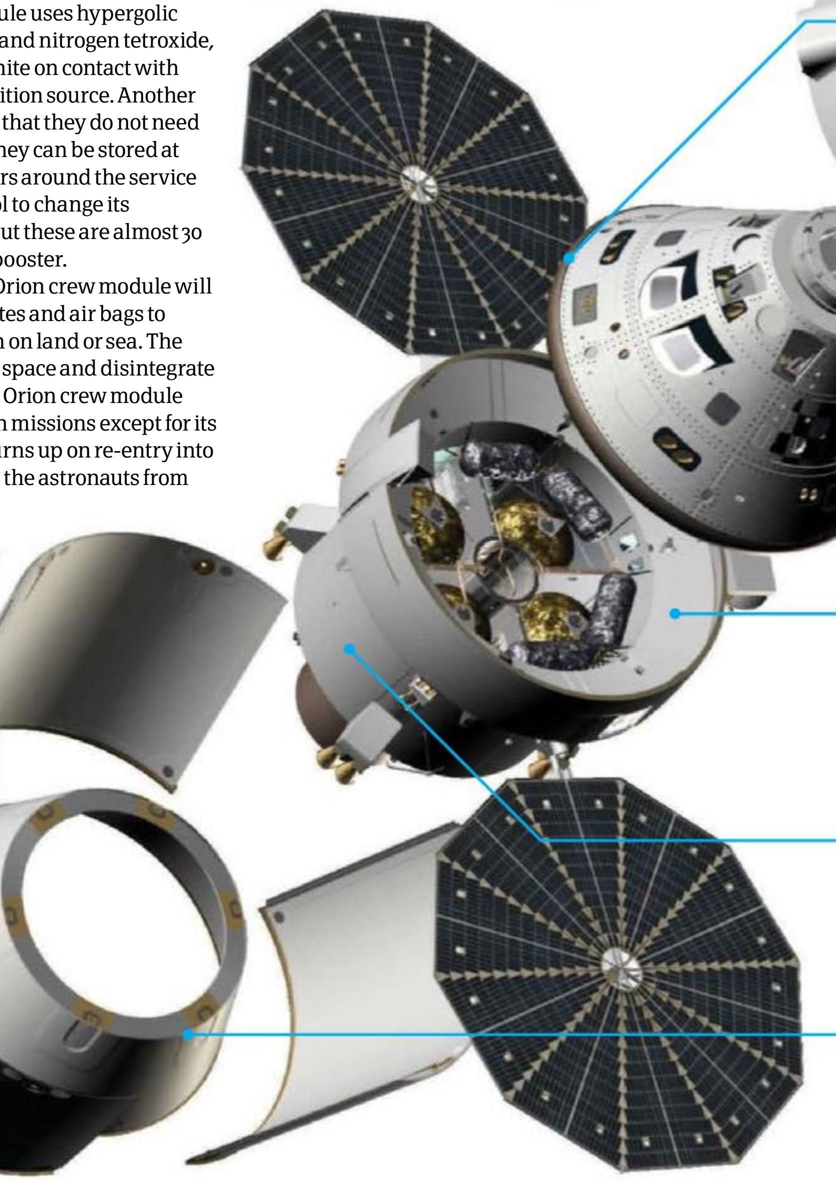
Upon descent to Earth the Orion crew module will use a combination of parachutes and air bags to allow a cushioned touchdown on land or sea. The service module will detach in space and disintegrate in the atmosphere. The entire Orion crew module will be reusable for at most ten missions except for its ablative heat shield, which burns up on re-entry into Earth's atmosphere to protect the astronauts from the extreme heat.

> "The crew module will use parachutes and air bags to allow a cushioned touchdown"

The first Orion missions will see it dock with the ISS to test its systems


The Orion spacecraft will transport a lunar lander to the moon

© NASA



5 TOP FACTS JAXA PROJECTS

Orion

1 Although Orion is currently still on schedule, there are murmurs that the project could be canned in favour of using private companies for transporting crew to the ISS.

SpaceX Dragon

2 One of the competitors, the Dragon capsule is currently undergoing cargo testing and could be ready to transport crew members to the ISS as early as 2017.

Boeing CST-100

3 After losing the Orion contract to Lockheed Martin, Boeing's capsule (similar in design to Orion) has been helped by $18m of funding from NASA and could launch by 2017.

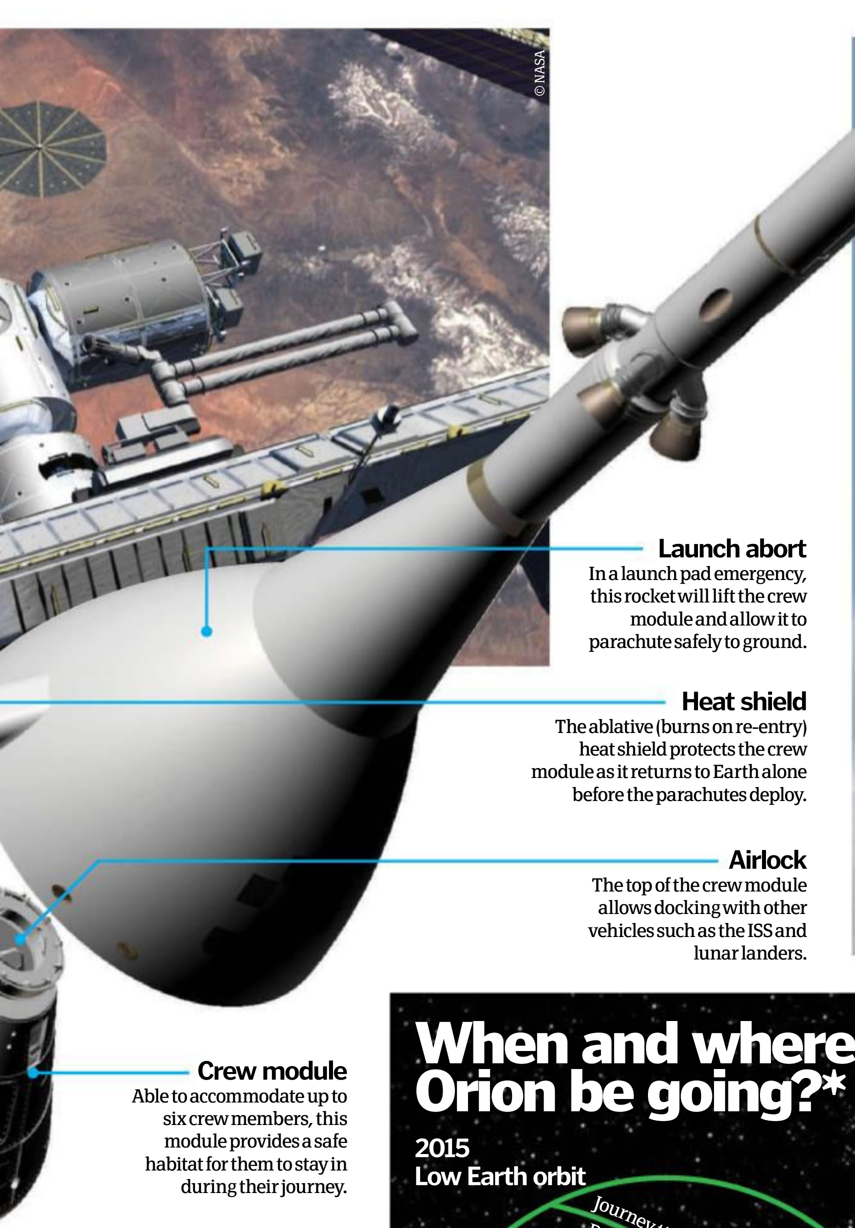
Dream Chaser

4 Under development by the Sierra Nevada Corporation, this space plane won $20m from a NASA competition. It could land on almost any runway in the world.

X-37B

5 This US military space plane returned from a seven month orbit in 2010 and made the first ever spacecraft landing by autopilot, but its intentions are unknown.

DID YOU KNOW? An Orion test module used over 150,000 ping-pong balls to stop it sinking after splashing down in the ocean


© NASA

Launch abort
In a launch pad emergency, this rocket will lift the crew module and allow it to parachute safely to ground.

Heat shield
The ablative (burns on re-entry) heat shield protects the crew module as it returns to Earth alone before the parachutes deploy.

Airlock
The top of the crew module allows docking with other vehicles such as the ISS and lunar landers.

Crew module
Able to accommodate up to six crew members, this module provides a safe habitat for them to stay in during their journey.

Service module
This module supports the crew throughout their journey, providing life support and propulsion, before detaching upon Earth re-entry.

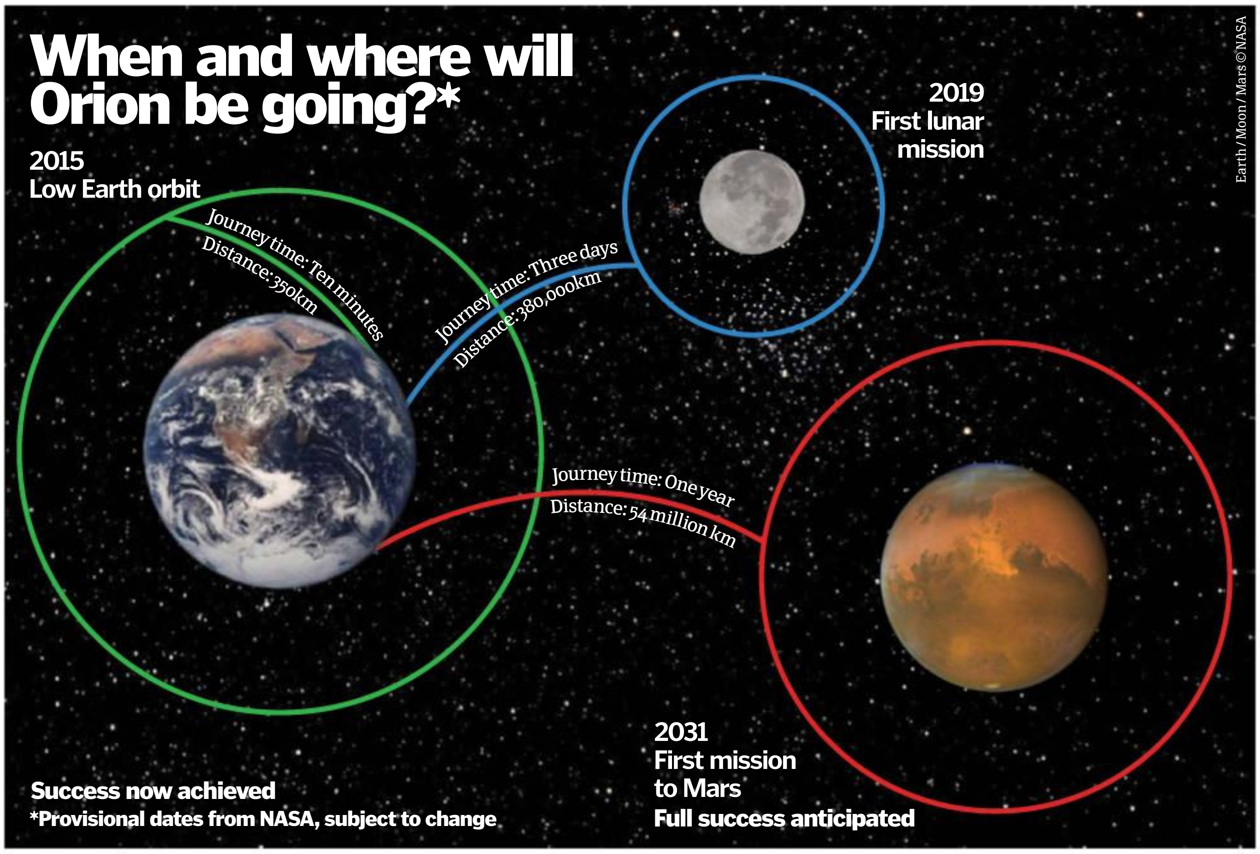
Cargo
Inside the service module, unpressurised cargo for the ISS and science equipment are stored.

Spacecraft adapter
Connects the Orion spacecraft to the launch rocket, and also protects components in the service module.

© NASA

The Launch Abort System will carry the crew module to safety in an emergency

When and where will Orion be going?*


2015
Low Earth orbit
Journey time: Ten minutes
Distance: 350km
Journey time: Three days
Distance: 380,000km
2019
First lunar mission
Journey time: One year
Distance: 54 million km
2031
First mission to Mars
Full success anticipated
Success now achieved

*Provisional dates from NASA, subject to change

Earth / Moon / Mars © NASA

> "When it is ready, VSS Unity should achieve altitudes of over 80 kilometres"

On board the SpaceShipTwo

Could this be the vehicle that will take you to space?

Virgin Galactic's reusable spaceplane, SpaceShipTwo, is designed to take two pilots and six passengers on the trip of a lifetime. Made by The Spaceship Company, part of Virgin Galactic, this vessel will be carried high into the atmosphere by the jet-powered aircraft WhiteKnightTwo, before engaging its rocket engines for a brief trip out of this world.

With 12 windows on the walls and ceiling to marvel at the view, and articulated seats for optimum journey comfort, it has been designed specifically with space tourism in mind. Passengers will be able to look up at the stars and down at the Earth below during a controlled flight in a spaceship that looks like a plane. After their adventure, they will glide back through the atmosphere, before landing on a runway.

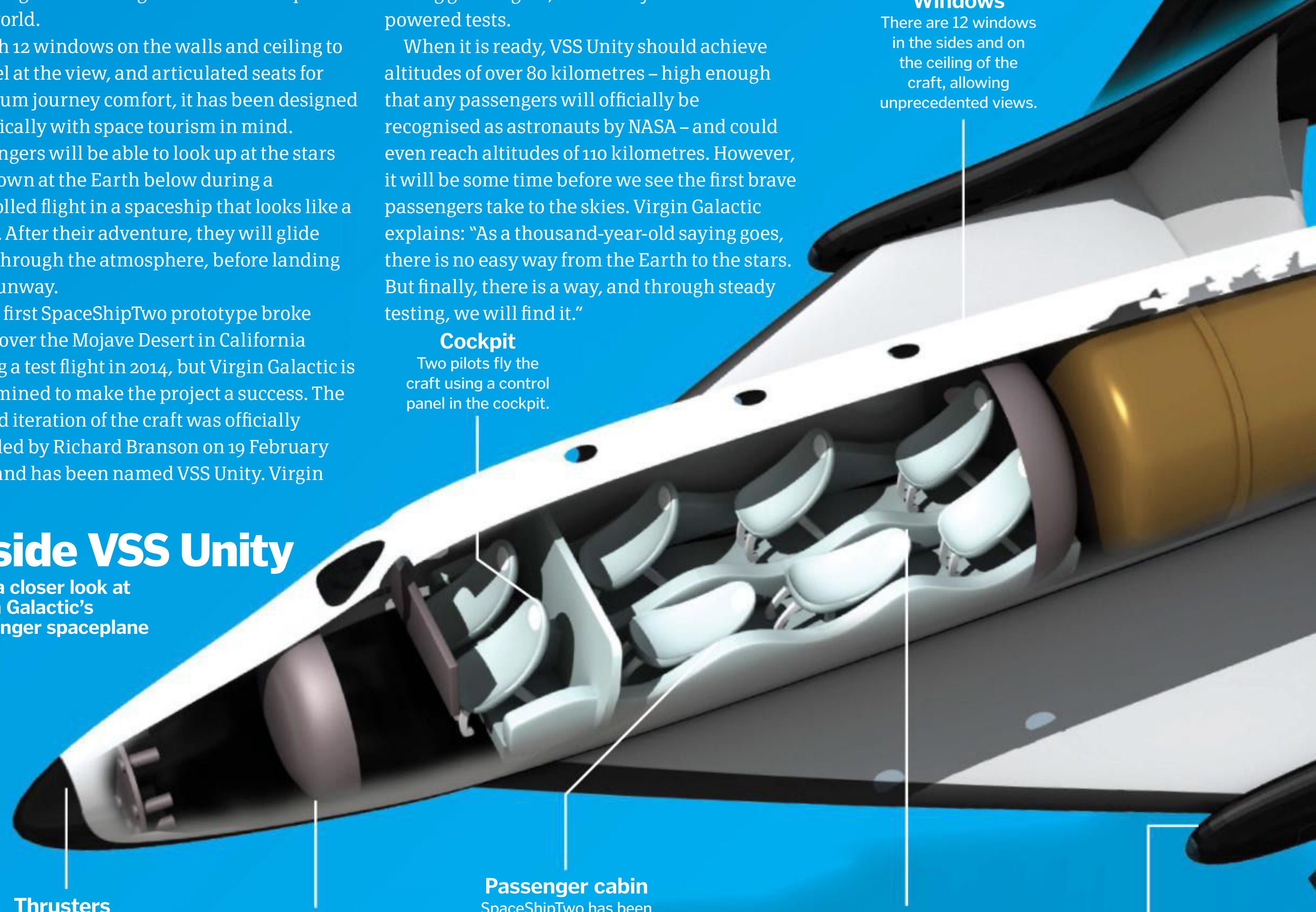
The first SpaceShipTwo prototype broke apart over the Mojave Desert in California during a test flight in 2014, but Virgin Galactic is determined to make the project a success. The second iteration of the craft was officially unveiled by Richard Branson on 19 February 2016, and has been named VSS Unity. Virgin Galactic is paying close attention to safety, commenting in a statement: "Starting at the level of individual pieces and components, we poked, prodded, stretched, squeezed, bent and twisted everything used to build these vehicles." The next step is to test the fully assembled spacecraft, first on the ground, then during glide flights, and finally in rocket-powered tests.

When it is ready, VSS Unity should achieve altitudes of over 80 kilometres – high enough that any passengers will officially be recognised as astronauts by NASA – and could even reach altitudes of 110 kilometres. However, it will be some time before we see the first brave passengers take to the skies. Virgin Galactic explains: "As a thousand-year-old saying goes, there is no easy way from the Earth to the stars. But finally, there is a way, and through steady testing, we will find it."

The first powered flight of VSS Enterprise shows the spaceplane in action

Inside VSS Unity

Take a closer look at Virgin Galactic's passenger spaceplane



Windows
There are 12 windows in the sides and on the ceiling of the craft, allowing unprecedented views.

Cockpit
Two pilots fly the craft using a control panel in the cockpit.

Thrusters
Positioned at the front of the spaceplane and on the wings, thrusters provide additional control during flight.

Fuselage
The body and nose of the plane are constructed from carbon fibre.

Passenger cabin
SpaceShipTwo has been designed with the passenger's experience in mind, aiming to minimise the discomfort of G-forces.

Articulated seats
The passenger seats are upright during ascent, and reclined during re-entry.

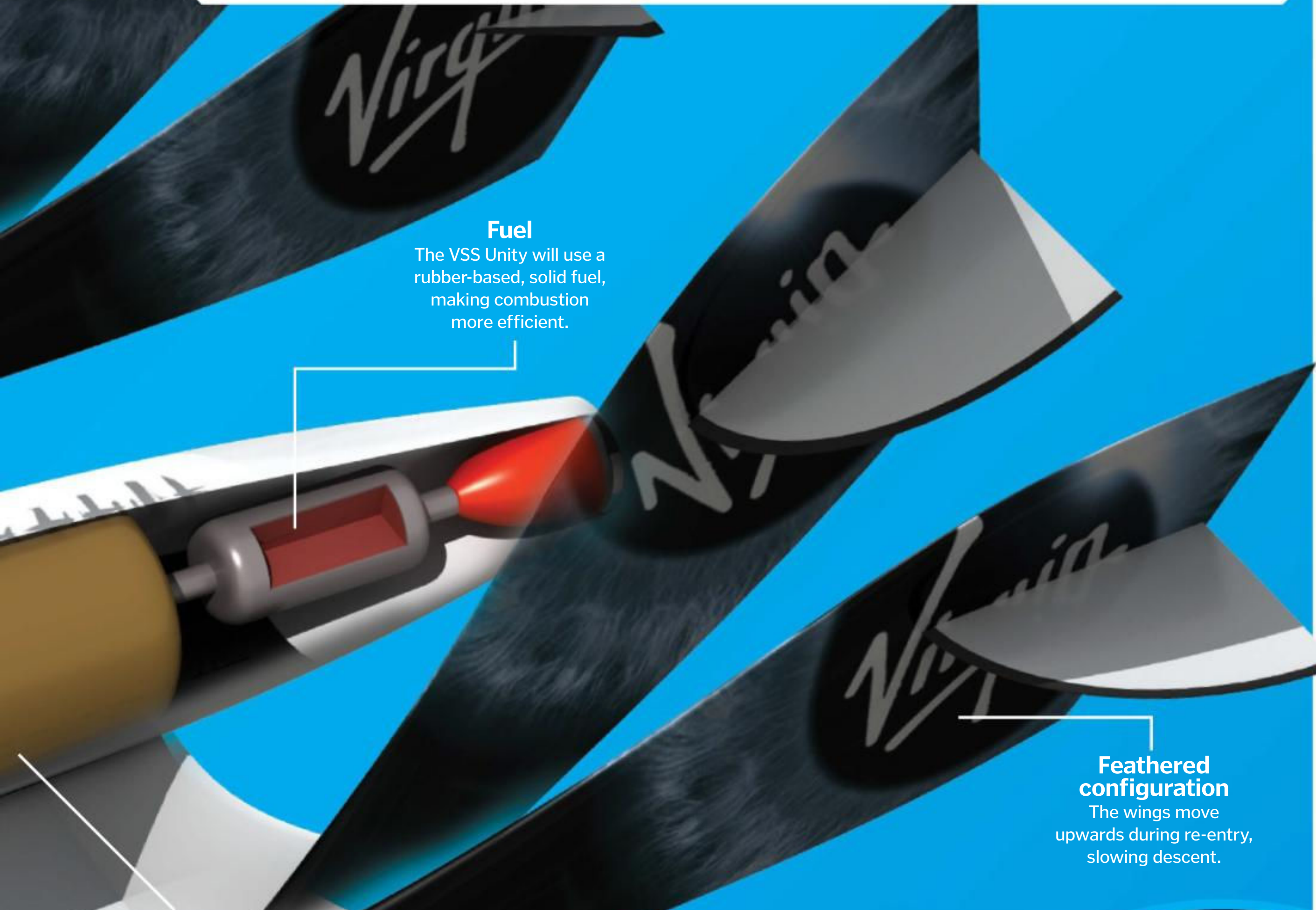
Thrusters

DID YOU KNOW? *There has only been one eight-person crew in space before, on board NASA's Space Shuttle Challenger*

VSS Enterprise crash

After 55 successful test flights, the first SpaceShipTwo, VSS Enterprise, broke apart over the Mojave Desert in California, killing co-pilot Michael Alsbury. SpaceShipTwo is equipped with a 'feathering system', designed to rotate the tail and wings for a smooth descent through Earth's atmosphere, but Alsbury unlocked it too early. With the rocket engine still firing, and with VSS Enterprise travelling at a little under the speed of sound, the feather system deployed, pulling the spaceplane apart. The other co-pilot, Peter Siebold, managed to parachute to safety. However, the computer system should have prevented the disaster, and it has been changed for the new SpaceShipTwo. This time, it will not be possible for the crew to unlock the feather system too soon.

The National Transportation Safety Board examines the remains of VSS Enterprise

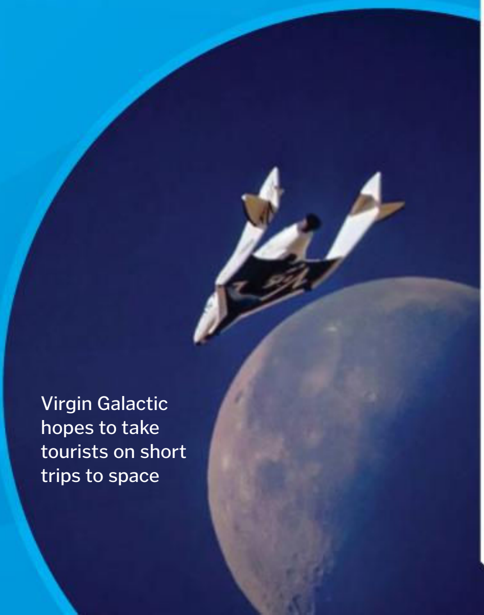

Fuel
The VSS Unity will use a rubber-based, solid fuel, making combustion more efficient.

Feathered configuration
The wings move upwards during re-entry, slowing descent.

Standard configuration
SpaceShipTwo can adopt two different configurations, behaving like a winged plane or a capsule.

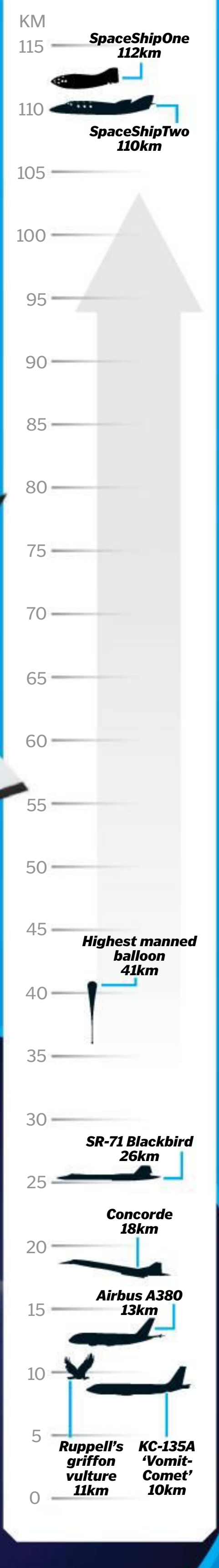
Nitrous oxide tank
The hybrid solid and liquid fuel engine can be shut down during the flight.

> *"We poked, prodded, stretched, squeezed, bent and twisted everything"*


Virgin Galactic hopes to take tourists on short trips to space

Flying high

See how SpaceShipTwo compares to other high fliers

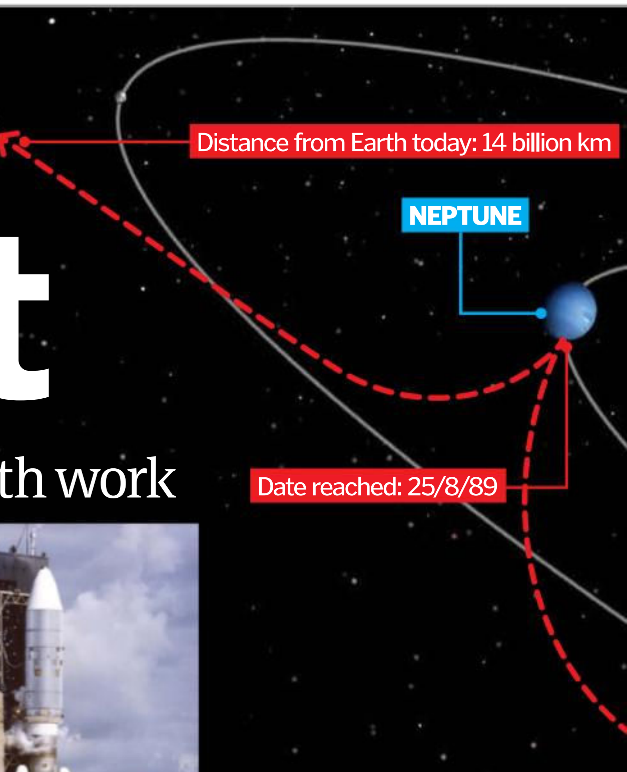


© Virgin Galactic; Illustration by Adrian Mann

> “The probes have studied all the major planets of the solar system past Mars”

Voyager spacecraft

How the furthest man-made objects from Earth work



On 20 August 1977 Voyager 2 launched from Cape Canaveral in Florida aboard a Titan-Centaur rocket, heralding the start of one of the most ambitious deep space exploration missions of all time. Two weeks later Voyager 1 was sent up in an identical launch, although its greater speed meant that it eventually overtook Voyager 2. The list of accomplishments by the two probes is astounding. Between them they have studied all of the major planets of the solar system past Mars, in addition to some moons of Jupiter and Saturn, making countless new discoveries in the process. Now, as the furthest man-made objects from Earth, they are on their way out of the solar system.

The launch of the mission coincided with a favourable alignment of the planets in the Seventies that would allow Voyager 2 to visit Jupiter, Saturn, Uranus and Neptune. The list of achievements by the two Voyager spacecraft is extensive. The Voyager mission was only the second – after Pioneer 10 and 11 in 1974 and 1975, respectively – to visit Jupiter and then Saturn, but it also discovered the existence of rings around Jupiter, while Voyager 2 was the first mission to visit Uranus and Neptune.

The primary objective of the mission was to study Jupiter and Saturn, but once it became apparent that the spacecraft could continue working, the mission was extended to include Neptune and Uranus for Voyager 2. Voyager 1 could have travelled to Pluto, but NASA decided to extend its mission to Saturn and its moon Titan, leaving the dwarf planet Pluto one of the largest bodies in the solar system yet to be explored.

The Voyager probes obtain power from their radioactive generators, which have kept them running even at such a great distance from Earth and will continue to do so until about 2020, when they will no longer be able to power their instruments. Voyager 1 is roughly now over 17 billion kilometres (10.6 billion miles) from the Sun, while Voyager 2 is at a distance of over 14 billion kilometres (8.5 billion miles).

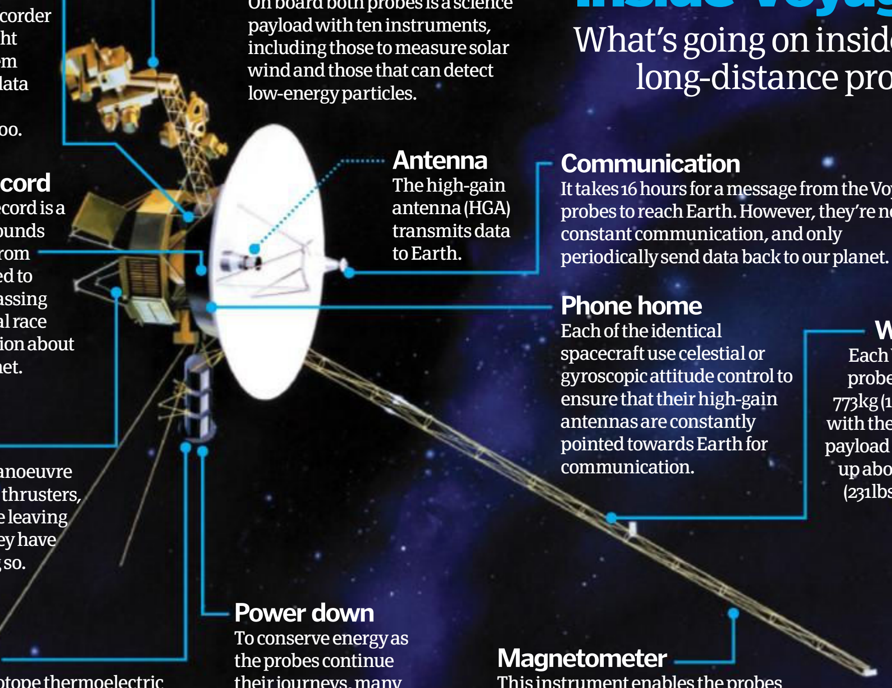
After making so many groundbreaking discoveries, both spacecraft are now on their way out of the solar system. They are both expected to pass out of the Sun’s influence and into interstellar space in the coming years, although it is not entirely clear when this will happen as no machine has yet experienced the conditions that the Voyager probes are about to endure.

In 40,000 years, Voyager 1 should be within 1.6 light years (9.4 trillion miles) of a star in the constellation of Camelopardalis thought to harbour a planetary system. 256,000 years later, Voyager 2 will be 4.3 light years (25 trillion miles) from Sirius, which is the brightest star other than the Sun in our night sky.

Voyager 2 launched atop a Titan III-Centaur rocket on 20 August 1977

Inside Voyager

What’s going on inside the long-distance probes?



Data
A single 8-track digital tape recorder (DTR) and Flight Data Subsystem (FDS) handle data and calibrate instruments too.

Instruments
On board both probes is a science payload with ten instruments, including those to measure solar wind and those that can detect low-energy particles.

Golden Record
The Golden Record is a collection of sounds and imagery from Earth, intended to provide any passing extraterrestrial race with information about our home planet.

Antenna
The high-gain antenna (HGA) transmits data to Earth.

Communication
It takes 16 hours for a message from the Voyager probes to reach Earth. However, they’re not in constant communication, and only periodically send data back to our planet.

Phone home
Each of the identical spacecraft use celestial or gyroscopic attitude control to ensure that their high-gain antennas are constantly pointed towards Earth for communication.

Weight
Each Voyager probe weighs 773kg (1,704lbs), with the science payload making up about 105kg (231lbs) of this.

Thrust
The probes manoeuvre via Hydrazine thrusters, although since leaving the planets they have stopped doing so.

Power down
To conserve energy as the probes continue their journeys, many instruments deemed unnecessary have or will be switched off.

Power up
Three radioisotope thermoelectric generators (RTGs) supply electrical power, which will eventually diminish but currently supply about 315 watts.

Magnetometer
This instrument enables the probes to measure nearby magnetic field intensities, which was used to study the magnetospheres of the outer planets.

5 TOP FACTS
VOYAGER DISCOVERIES

Moons
1 Around the outer planets the Voyager probes discovered 23 new moons, including five around Saturn and 11 around Uranus, in addition to imaging our own.

Interstellar medium
2 Both of the Voyager probes are now in a region where the Sun's influence is increasingly waning, and soon they will enter the interstellar medium.

Atmospheres
3 Voyager probes 1 and 2 both provided unprecedented information about the atmospheres of the following planets: Jupiter, Saturn, Uranus and Neptune.

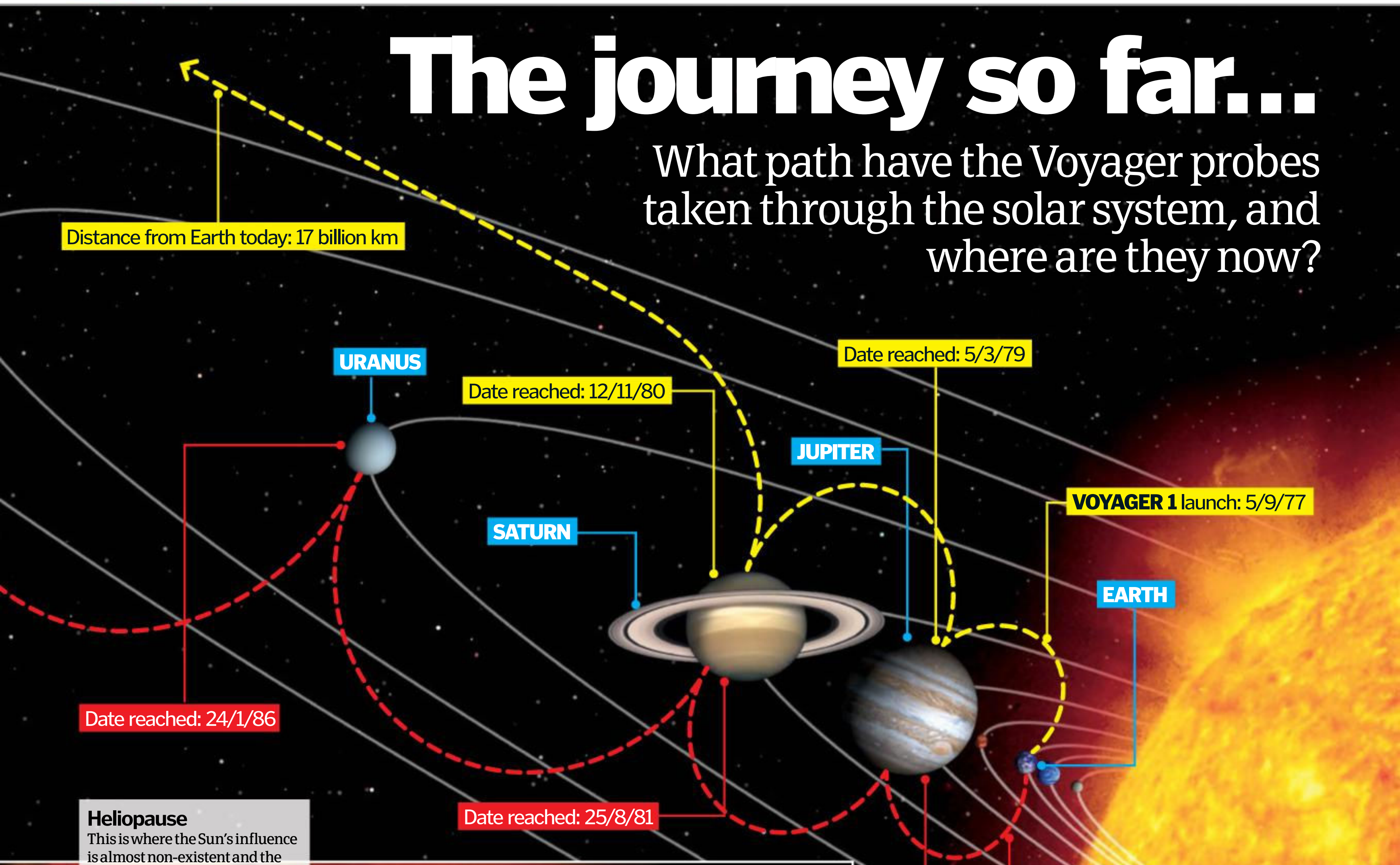
Jupiter
4 The probes discovered for the first time a ring system encircling Jupiter, and they also observed hurricane-like storms in the planet's atmosphere.

Io
5 Voyager 1 discovered the only known body in the solar system other than Earth to be volcanically active: Jupiter's moon Io. This moon also affects the surrounding Jovian system.

DID YOU KNOW? *Voyager 1 is now travelling at 38,000mph, while Voyager 2 is slightly slower at 35,000mph*

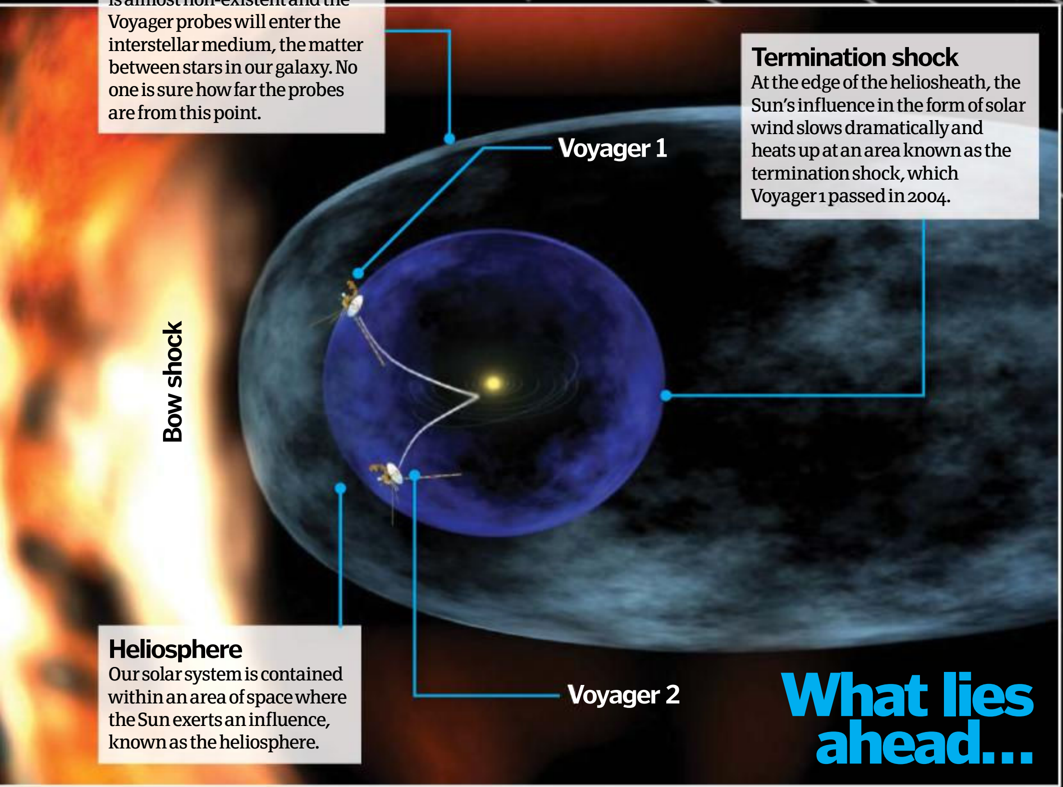
The journey so far…

What path have the Voyager probes taken through the solar system, and where are they now?



Distance from Earth today: 17 billion km
URANUS
Date reached: 12/11/80
Date reached: 5/3/79
JUPITER
VOYAGER 1 launch: 5/9/77
SATURN
EARTH
Date reached: 24/1/86
Date reached: 25/8/81
VOYAGER 2 launch: 20/8/77
Date reached: 9/7/79

What lies ahead…

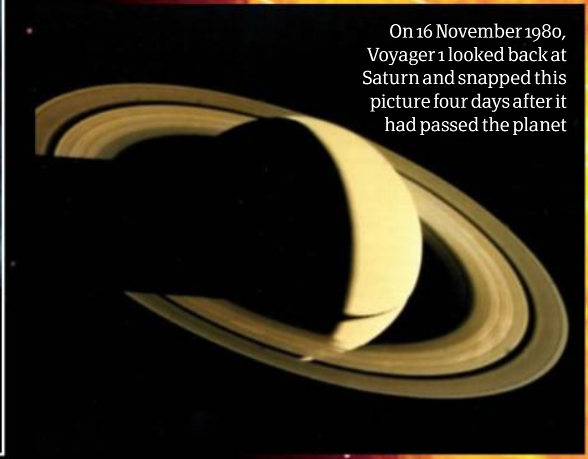


Voyager 1
Voyager 2
Bow shock

Heliopause
This is where the Sun's influence is almost non-existent and the Voyager probes will enter the interstellar medium, the matter between stars in our galaxy. No one is sure how far the probes are from this point.

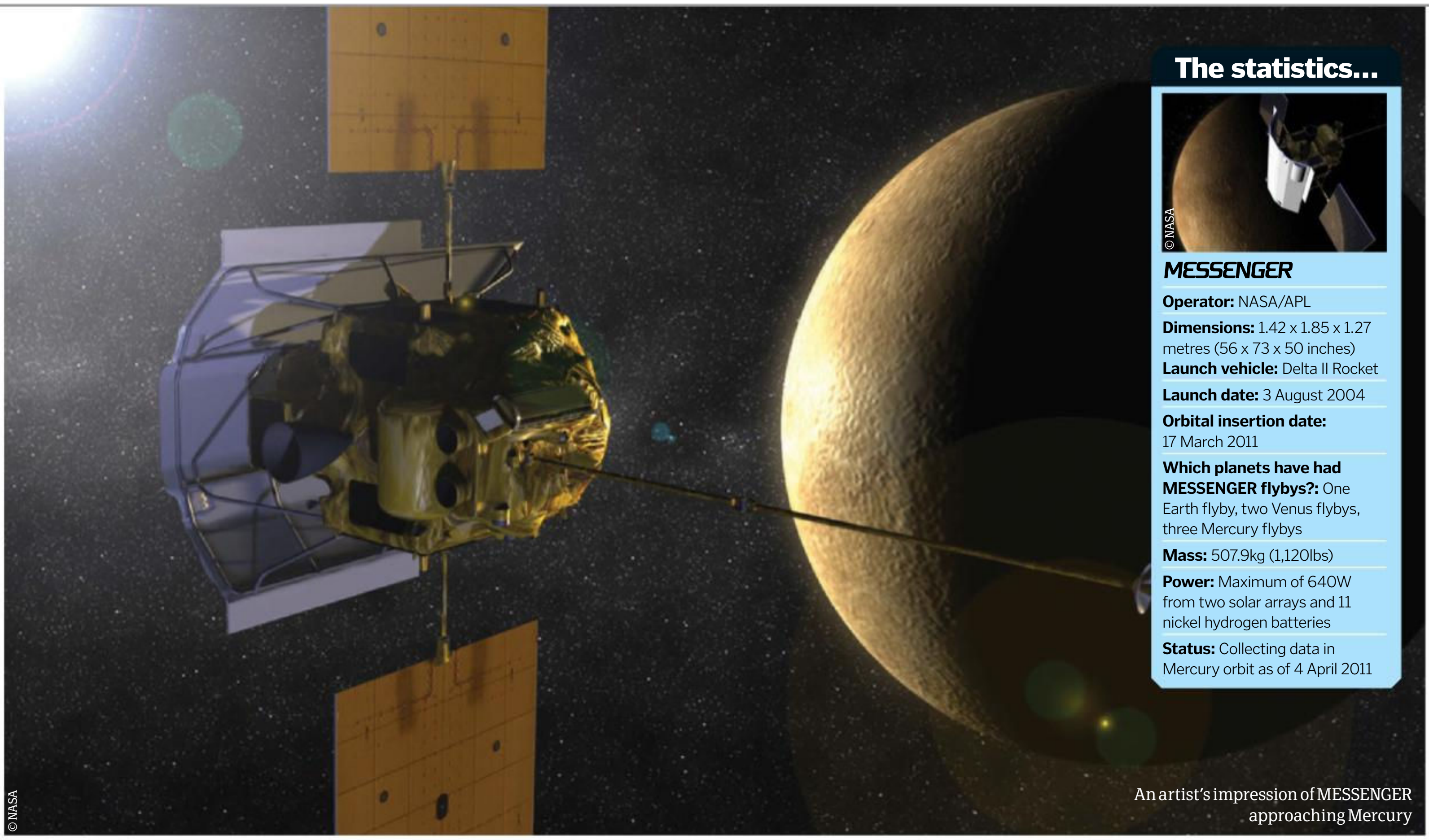
Termination shock
At the edge of the heliosheath, the Sun's influence in the form of solar wind slows dramatically and heats up at an area known as the termination shock, which Voyager 1 passed in 2004.

Heliosphere
Our solar system is contained within an area of space where the Sun exerts an influence, known as the heliosphere.


On 16 November 1980, Voyager 1 looked back at Saturn and snapped this picture four days after it had passed the planet

All images © NASA

"MESSENGER's mission comprises six main goals"



© NASA

The statistics...

© NASA

MESSENGER

Operator: NASA/APL

Dimensions: 1.42 x 1.85 x 1.27 metres (56 x 73 x 50 inches)

Launch vehicle: Delta II Rocket

Launch date: 3 August 2004

Orbital insertion date: 17 March 2011

Which planets have had MESSENGER flybys?: One Earth flyby, two Venus flybys, three Mercury flybys

Mass: 507.9kg (1,120lbs)

Power: Maximum of 640W from two solar arrays and 11 nickel hydrogen batteries

Status: Collecting data in Mercury orbit as of 4 April 2011

An artist's impression of MESSENGER approaching Mercury

The MESSENGER probe

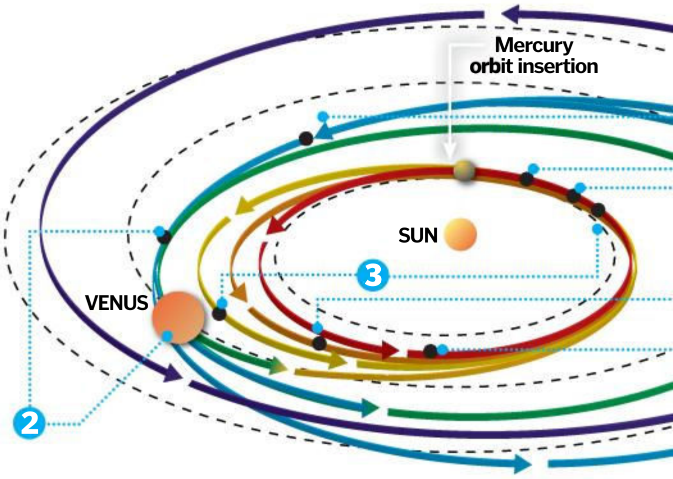
Discover the first spacecraft to explore Mercury since 1975

MESSENGER, an acronym short for MErcury Surface, Space ENvironment, GEochemistry and Ranging, is a probe launched by NASA in 2004 to study the planet Mercury in our Solar System. After a journey of 7.9 billion kilometres (4.9 billion miles), MESSENGER finally entered Mercury's orbit on 17 March 2011.

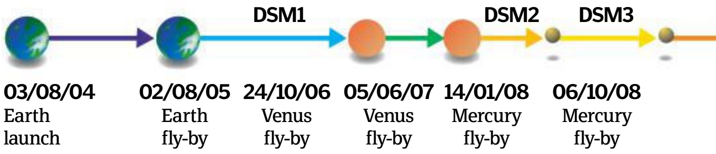
Mercury has remained one of the most mysterious planets in the solar system, not having been studied closely since Mariner 10's flybys more than three decades ago. In addition to being the smallest inner planet, Mercury is also the most dense and has the oldest surface. Scientists believe that learning more about Mercury will help us to better understand how the other terrestrial planets – Venus, Earth and Mars – came to be.

MESSENGER's mission comprises six main goals. It will determine the structure of Mercury's core, reveal why the planet is so dense, find out the nature of its magnetic field, measure the gases in the exosphere, solve the mystery of unusual materials at the poles, and delve into the planet's geologic past. Although launched by NASA, MESSENGER was designed and built at the Applied Physics Laboratory at Johns Hopkins University. It carries seven instruments to collect data and images, housed together on a small pallet. MESSENGER also has two rotatable solar panels, which generate energy stores in batteries, as well as a large thruster for deep space manoeuvres, four smaller thrusters for steering, deep space transponders and antennae for communication and an integrated electronics module that allows it to be controlled from the ground.

MESSENGER had already made some significant discoveries before entering Mercury's orbit. During the flybys of the planet, the probe surprised NASA by revealing that the upper layer of Mercury's atmosphere contained water. It also collected data suggesting that the planet has a liquid core and may have had volcanic activity in the past. MESSENGER is scheduled to send back data and images from Mercury's orbit for one year. When it was no longer operational, the probe crashed into the planet.

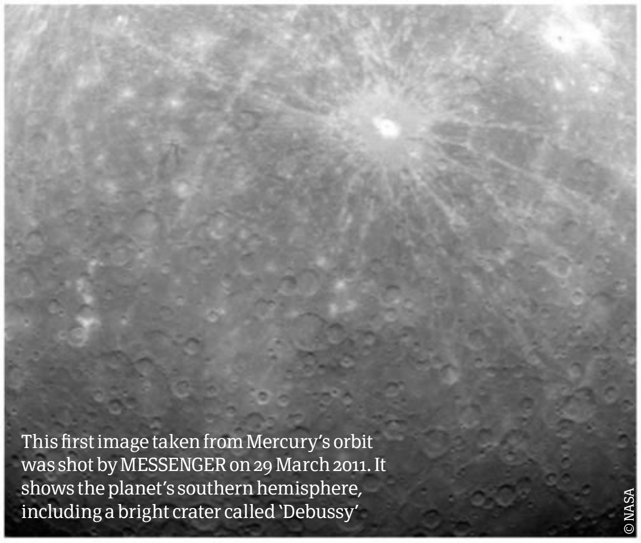


MESSENGER flyby dates



Voyage to Mercury

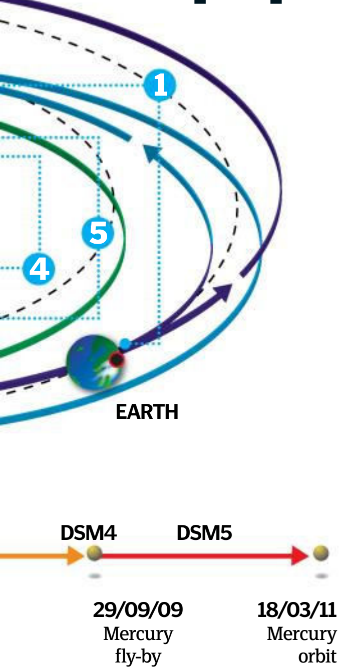
NASA didn't send another spacecraft to explore Mercury for so long because it would have required a very large, powerful launch vehicle and too much fuel for the mission to be practical. In 1985, scientist Chen-wan Yen suggested a trajectory that would ultimately allow a probe to launch as part of NASA's low-cost Discovery program. The probe could not be launched on a direct path to enter Mercury's orbit, because the gravity of the Sun would have accelerated it right past the planet. Instead, in a series of flybys (of Earth, Venus and Mercury itself) the probe used each planet's gravity field to slow down. Deep space manoeuvres, in which MESSENGER fired its rocket thruster for anywhere from a few seconds to a few minutes, allowed the probe to speed up when necessary or change course. While it took almost seven years to reach Mercury, this also meant that the probe used very little fuel.



This first image taken from Mercury's orbit was shot by MESSENGER on 29 March 2011. It shows the planet's southern hemisphere, including a bright crater called 'Debussy'

© NASA

MESSENGER flybys and deep space manoeuvres



1. Earth flyby and DSM 1

The Earth flyby took place on 2 August 2005. Then the probe made its first DSM by firing its large thruster to change trajectory towards Venus.

2. Venus flybys and DSM 2

On 24 October 2006 and 5 June 2007, MESSENGER conducted flybys of Venus. Another DSM resulted in a course correction to put the probe closer to Mercury's orbit.

3. Mercury flyby 1 and DSM 3

The probe reached Mercury on 14 January 2008, then fired its thrusters again to speed things up for another flyby.

4. Mercury flyby 2 and DSM 4

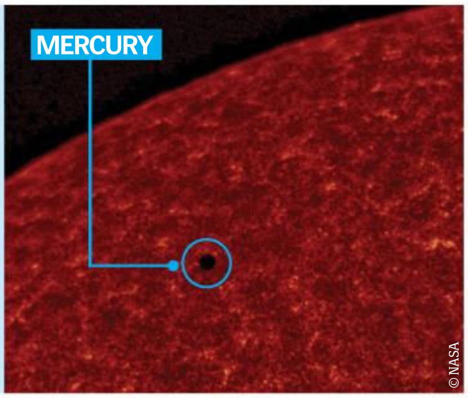
On 6 October 2008, Mercury conducted another flyby of Mercury. A fourth DSM slowed the probe to allow it to be 'captured' by Mercury's gravitational field.

5. Mercury flyby 3 and DSM 5

The third and final flyby of Mercury took place on September 29 2009. The fifth DSM, on 24 November 2009, slowed the probe further for entry into Mercury's orbit.

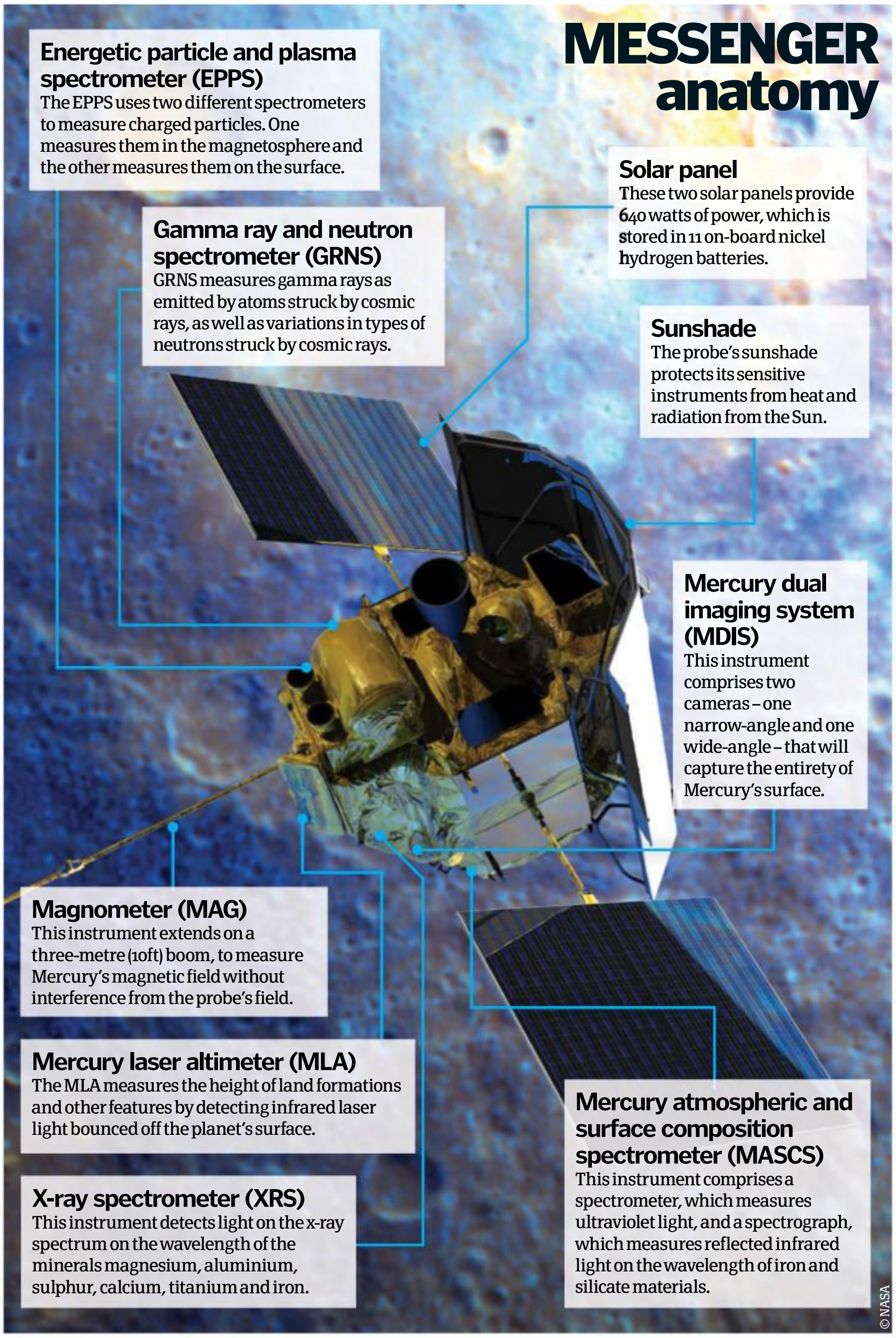
Hiding near the Sun

As the innermost planet, Mercury's orbit gets no further than 70 million kilometres (43.5 million miles) from the Sun, compared with Earth's 152 million-kilometre (94.4 million-mile) orbit. This closeness means that the planet is difficult to see from Earth, because it gets lost in the Sun's glow. It can sometimes be seen during sunrise or sunset, depending on your location and the time of year.



© NASA

MESSENGER anatomy



Energetic particle and plasma spectrometer (EPPS)
The EPPS uses two different spectrometers to measure charged particles. One measures them in the magnetosphere and the other measures them on the surface.

Gamma ray and neutron spectrometer (GRNS)
GRNS measures gamma rays as emitted by atoms struck by cosmic rays, as well as variations in types of neutrons struck by cosmic rays.

Solar panel
These two solar panels provide 640 watts of power, which is stored in 11 on-board nickel hydrogen batteries.

Sunshade
The probe's sunshade protects its sensitive instruments from heat and radiation from the Sun.

Mercury dual imaging system (MDIS)
This instrument comprises two cameras – one narrow-angle and one wide-angle – that will capture the entirety of Mercury's surface.

Magnometer (MAG)
This instrument extends on a three-metre (10ft) boom, to measure Mercury's magnetic field without interference from the probe's field.

Mercury laser altimeter (MLA)
The MLA measures the height of land formations and other features by detecting infrared laser light bounced off the planet's surface.

X-ray spectrometer (XRS)
This instrument detects light on the x-ray spectrum on the wavelength of the minerals magnesium, aluminium, sulphur, calcium, titanium and iron.

Mercury atmospheric and surface composition spectrometer (MASCS)
This instrument comprises a spectrometer, which measures ultraviolet light, and a spectrograph, which measures reflected infrared light on the wavelength of iron and silicate materials.

© NASA

The target altitude is 40,000m (130,000ft)

> "The balloon will be almost 75 metres (245 feet) tall and, once it has expanded in the thin atmosphere, it will reach a diameter of 100 metres (330 feet)"

Big Space Balloon

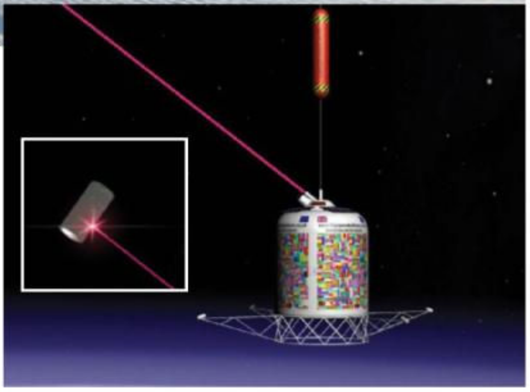
How will this giant balloon perform experiments at the edge of space?

The Big Space Balloon will be Britain's largest high-altitude research balloon, taking experiments up to the edge of the cosmos and exploring the upper echelons of Earth's atmosphere. Once it has been funded it will launch, carrying a capsule full of scientific experiments to study the Earth and its atmosphere, before returning to our planet and possibly being re-launched in the future.

The balloon will be almost 75 metres (245 feet) tall and, once it has expanded in the thin atmosphere, it will reach a diameter of 100 metres (330 feet) and a volume of 400,000 cubic metres (14 million cubic feet). It has been designed to provide a low-cost alternative to taking a payload into orbit compared to an expensive rocket launch. The entire balloon and capsule system will be roughly twice the height of Nelson's Column and almost as wide as the height of the most powerful rocket of all time, the Saturn V. The design is a super-pressure balloon envelope, which is designed to survive several days at the border of space. The balloon material will be made from 100 per cent recycled polythene.

Attached to the balloon by a cable will be a capsule 2.9 metres (9.5 feet) tall and two metres (6.5 feet) wide. This will be made from the latest composite materials for strength and durability. Filled with scientific instruments, the capsule will study the Earth and its atmosphere from a height of 40,000 metres (130,000 feet). At the end of its mission the capsule will parachute safely back to Earth, where it will be recovered and potentially used again in other similar missions.

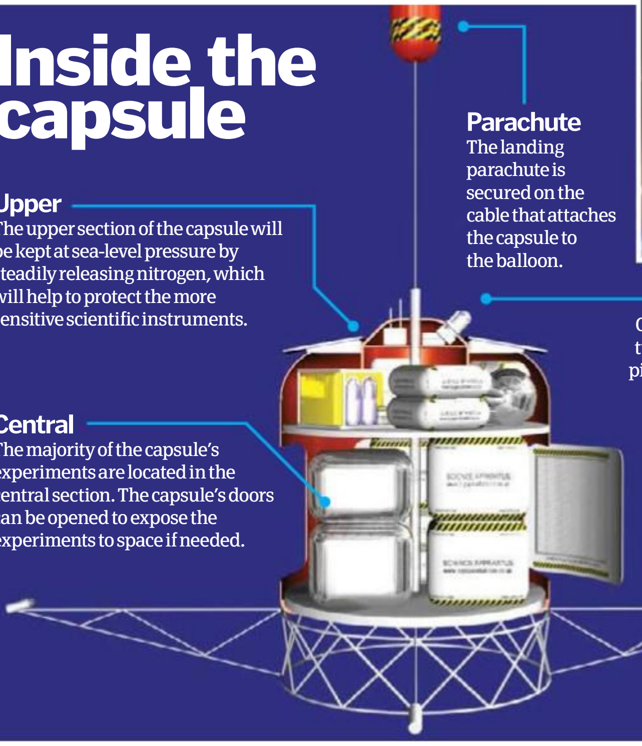
A laser may be installed in order to push space debris out of harm's way



A concept shot of the balloon envelope at the launch site

DID YOU KNOW? *The Big Space Balloon is raising funds by selling advertising space for logos on the exterior of the capsule*

Inside the capsule



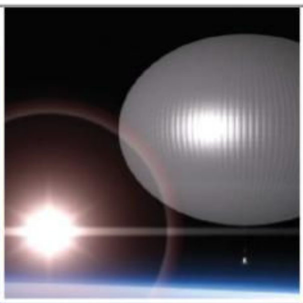
Upper
The upper section of the capsule will be kept at sea-level pressure by steadily releasing nitrogen, which will help to protect the more sensitive scientific instruments.

Central
The majority of the capsule's experiments are located in the central section. The capsule's doors can be opened to expose the experiments to space if needed.

Parachute
The landing parachute is secured on the cable that attaches the capsule to the balloon.

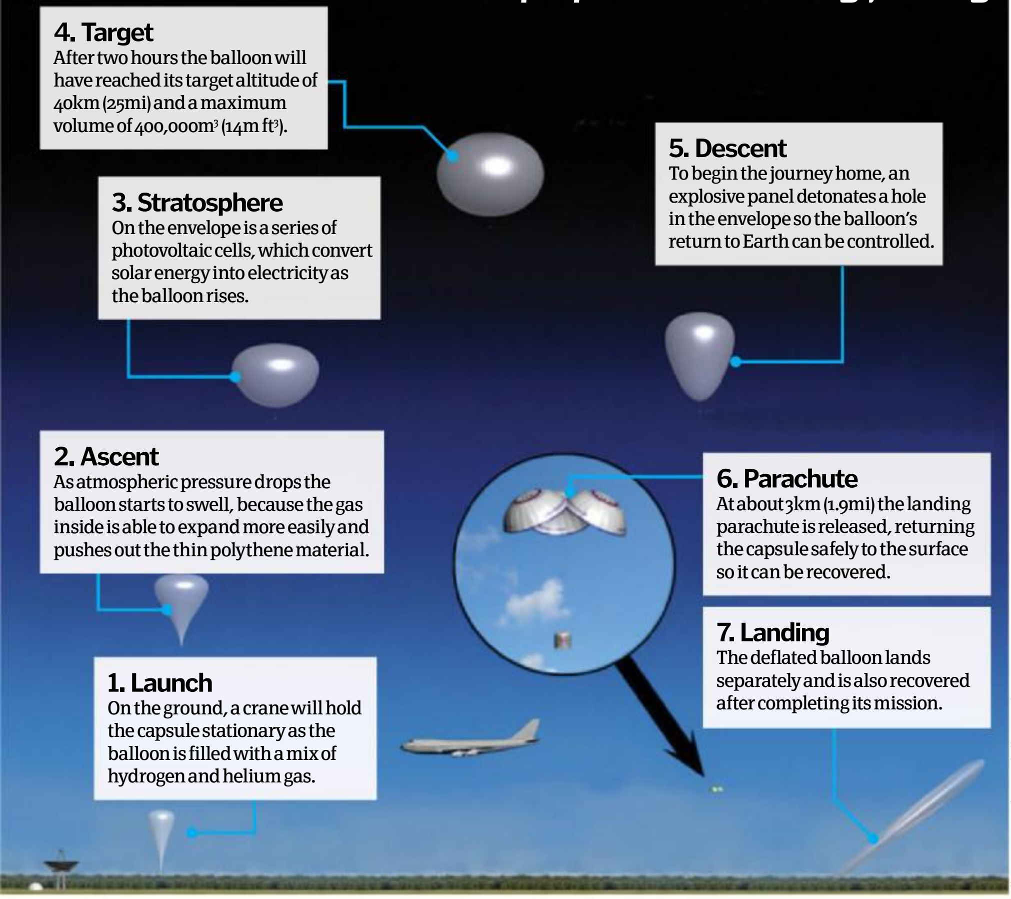
Debris
One proposed experiment is a laser turret, which could be used to push pieces of space debris out of the way.

Cameras
The capsule will be monitored by four cameras surrounding it, which will also highlight sponsorship logos on the outside of the capsule.



THE MISSION STEP BY STEP

We take a look at the Big Space Balloon's proposed seven-day journey



1. Launch
On the ground, a crane will hold the capsule stationary as the balloon is filled with a mix of hydrogen and helium gas.

2. Ascent
As atmospheric pressure drops the balloon starts to swell, because the gas inside is able to expand more easily and pushes out the thin polythene material.

3. Stratosphere
On the envelope is a series of photovoltaic cells, which convert solar energy into electricity as the balloon rises.

4. Target
After two hours the balloon will have reached its target altitude of 40km (25mi) and a maximum volume of 400,000m³ (14m ft³).

5. Descent
To begin the journey home, an explosive panel detonates a hole in the envelope so the balloon's return to Earth can be controlled.

6. Parachute
At about 3km (1.9mi) the landing parachute is released, returning the capsule safely to the surface so it can be recovered.

7. Landing
The deflated balloon lands separately and is also recovered after completing its mission.

All images © www.bigspaceballoon.co.uk

Interview Richard Curtis

We speak to the project director of the Big Space Balloon mission

How It Works: How and why did you get involved with this project?
Richard Curtis: The Big Space Balloon is an idea I've been working on for a couple of years. I was part of the generation growing up during the Apollo missions, Skylab, Soyuz and then the Space Shuttle, so I've had a lifelong interest in space and space tech. It would be very exciting to use some of the latest technologies such as printed solar cells and additive layer manufacturing to build a substantial vehicle and send it on its way to the edge of space and see the images of the Big Space Balloon flying above the Earth's atmosphere.

HIW: Why did you pick a balloon for this project?
RC: A big stratospheric balloon allows you to lift a reasonably substantial payload of up to several tons into a space environment. The Big Space Balloon will be aiming for a total payload weight – including the science capsule – of around one ton. This should allow us to carry up to half a ton of science equipment. Although there is now a lot of great science being done with mini-payloads and balloons, there are still areas where the bigger the kit the better, particularly with imaging and sensing devices.

HIW: Is there any danger in launching this balloon?
RC: There is a range of challenges [we may face]. The main one is the balloon fabric tearing during launch. The material used for most large stratospheric projects tends to be a very lightweight polythene, similar in thickness to a supermarket carrier bag. Hopefully we've arrived at a size that's [thin enough but durable]. I'm also hoping that by combining the fabric with printed solar cells we can make a stronger composite balloon material. This will probably mean a heavier fabric, but as we're not trying to break any altitude records, it's not too critical if we only achieve, say, [38,000 metres] 125,000 feet instead of [41,000 metres] 135,000.

HIW: What does the future hold for space balloons?
RC: The hope is that the Big Space Balloon's science capsule could be reused in further missions. I'm keen for the Big Space Balloon to act as a platform to test out new technologies in the space environment, such as printed solar cells on the balloon envelope, which could pave the way for a new way of powering future spacecraft or stations. Additive layer manufacturing (aka 3D printing) is another process I'm aiming to use in the fabrication of the science capsule, as this allows fairly complex and bespoke structures to be manufactured straight from the computer.

There's also the possibility of using the technology for interplanetary missions. One of the instruments the science capsule may carry could be to detect micro-organisms in the Earth's upper atmosphere – technology that could be then transferable to a future Mars or Venus mission.

> *"In the case of human payloads, these were delivered via an airlock located at the front of the shuttle"*

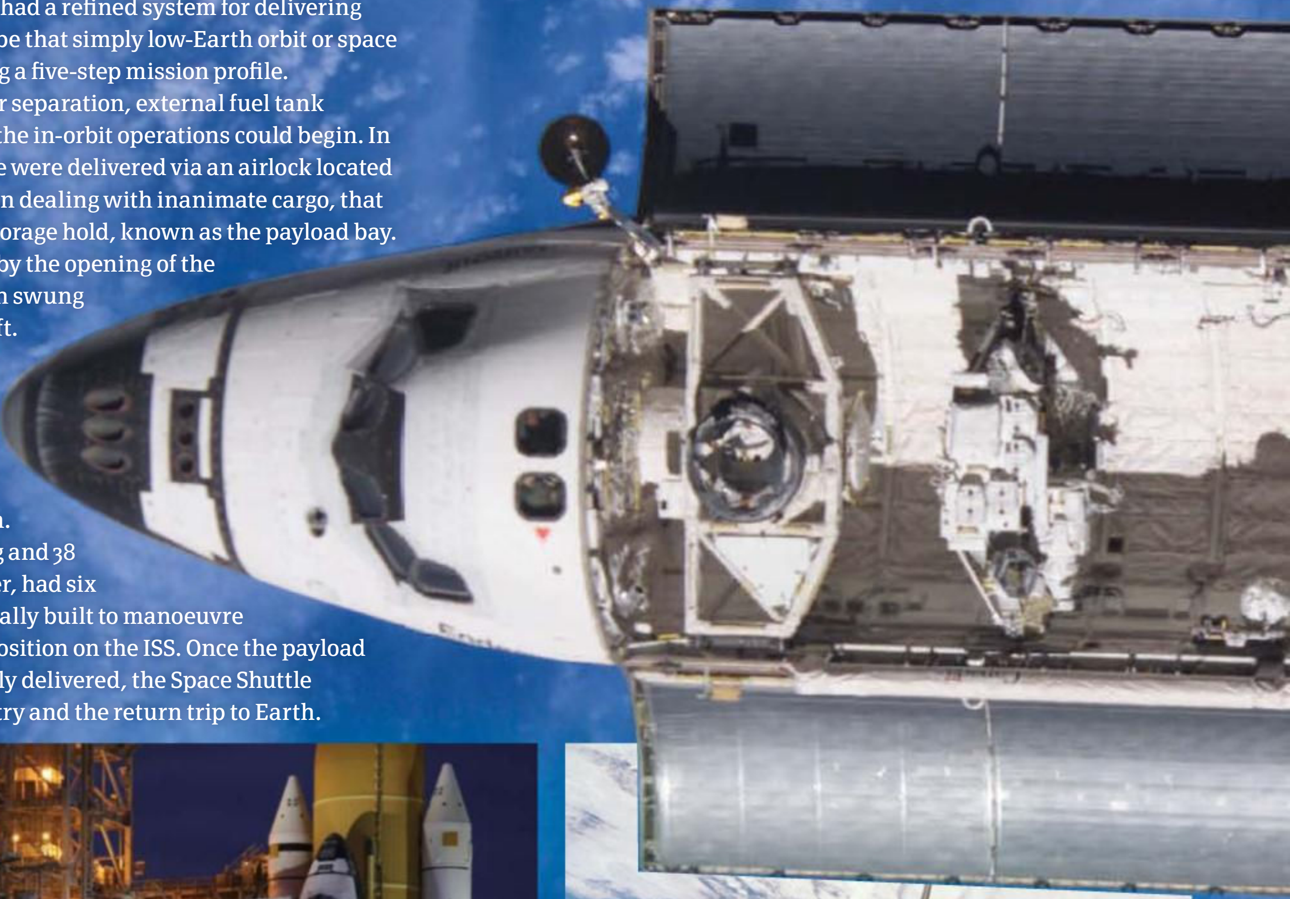
Space Shuttle payload bay

How did this colossus deliver tons of supplies and technology into space?

NASA's Space Shuttle launch vehicles undertook over 130 missions during their lifetime, carrying hundreds of tons of technology into space. It had a refined system for delivering payloads to the intended target – be that simply low-Earth orbit or space stations such as the ISS – following a five-step mission profile.

After liftoff, solid-rocket booster separation, external fuel tank separation and orbital insertion, the in-orbit operations could begin. In the case of human payloads, these were delivered via an airlock located at the front of the shuttle, but when dealing with inanimate cargo, that required accessing the internal storage hold, known as the payload bay. Tech and supplies were accessed by the opening of the shuttle's payload bay doors, which swung open from the top of the spacecraft.

Once the bay doors were open, the resources within could be collected either by an EVA (extravehicular activity, or spacewalk), or using a robotic mechanical arm called Canadarm. This arm, 15.2 metres (50 feet) long and 38 centimetres (15 inches) in diameter, had six degrees of freedom and was specially built to manoeuvre cargo from the bay to their final position on the ISS. Once the payload for a mission had been successfully delivered, the Space Shuttle would then be prepared for re-entry and the return trip to Earth.



The STS-133 payload canister is lifted into the rotating service structure on Launch Pad 39A

The Canadarm being used to retrieve cargo from within the Space Shuttle

22,753kg

BIGGEST PAYLOAD TO SPACE

The heaviest non-commercial payload ever launched – the Chandra X-ray Observatory – weighed in at 22,753 kilograms (50,161 pounds) on Space Shuttle mission STS-93 in 1999.

DID YOU KNOW? *The last Space Shuttle launch – STS-135 – carried a payload of 3,630kg (8,000lb) of supplies*

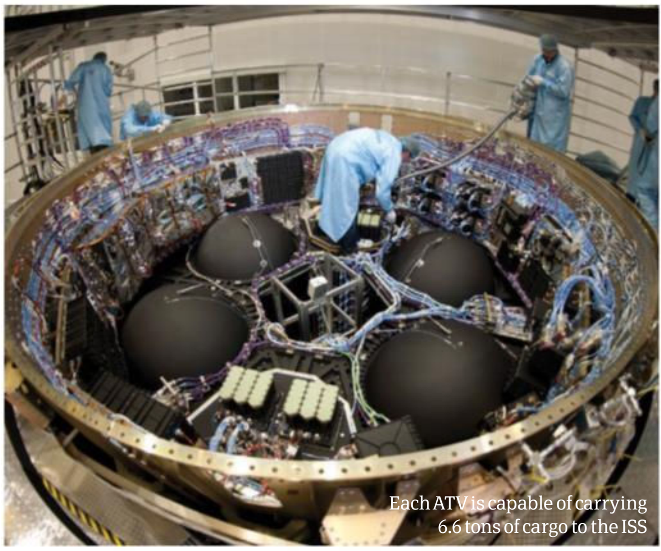
Endeavour
NASA

Endeavour in flight clearly showing its spacious payload bay on STS-111

© NASA

Automated transfer vehicles

How do these European resupply craft keep the ISS fully stocked?



Each ATV is capable of carrying 6.6 tons of cargo to the ISS

© ESA

The European Space Agency's automated transfer vehicles (ATVs) are unmanned spacecraft designed to take cargo and supplies to the International Space Station (ISS), before detaching and burning up in Earth's atmosphere. They are imperative in maintaining a human presence on the ISS, bringing various life essentials to the crew such as water, food and oxygen, in addition to new equipment and tools for conducting experiments and general maintenance of the station.

The first ATV to fly was the Jules Verne ATV-1 in 2008; it was named after the famous 19th-century French author who wrote *Around The World In 80 Days*. This was followed by the (astronomer) Johannes Kepler ATV-2 in February 2011, and will be succeeded by the (physicists) Edoardo Amaldi and Albert Einstein ATVs in 2012 and 2013, respectively.

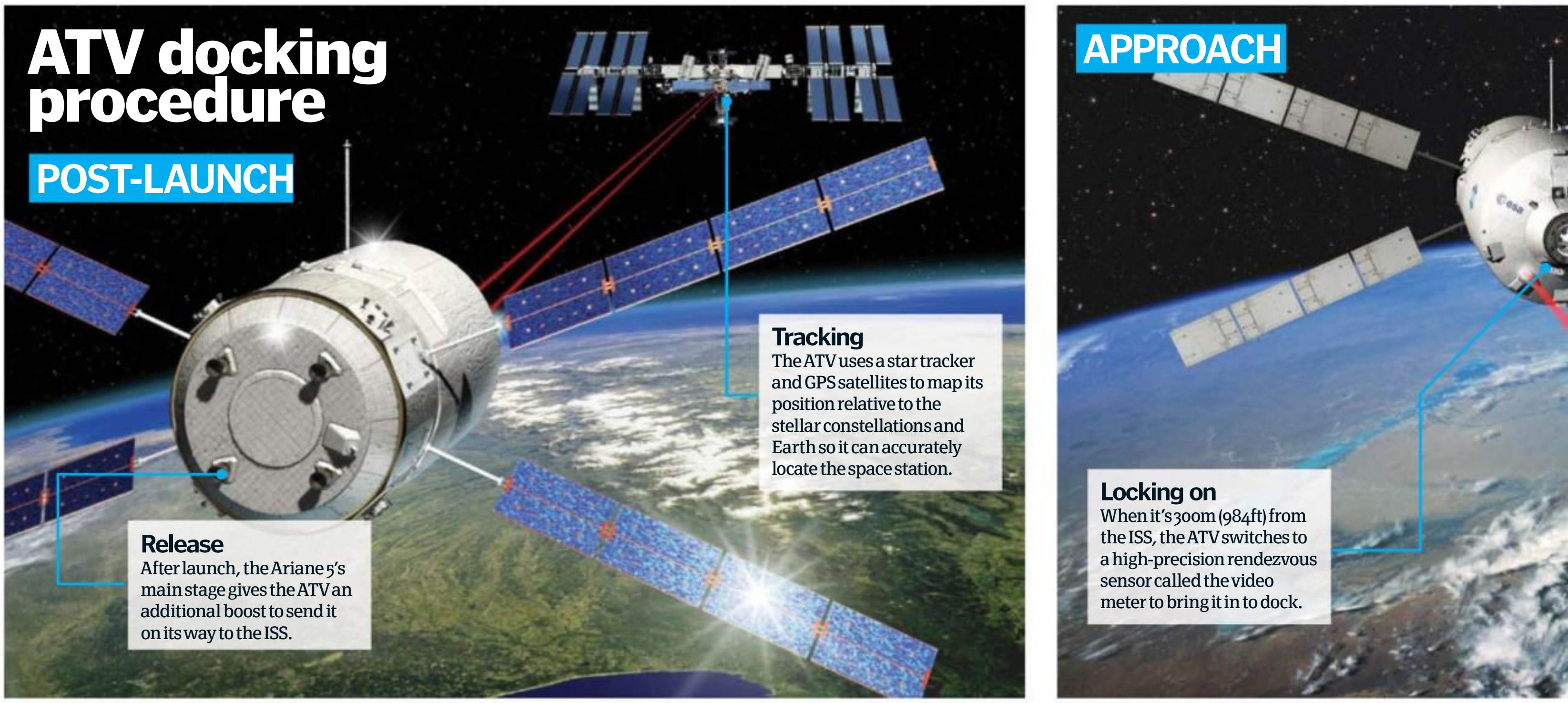
The ATV-1 mission differed somewhat from the subsequent ones as it was the first of its kind attempted by the ESA and thus various additional procedures were carried out, such as testing the vehicle's ability to manoeuvre in close proximity to the ISS for several days to prevent it damaging the station when docking. However, for the most part, all ATV missions are and will be the same.

ATVs are launched into space atop the ESA's Ariane 5 heavy-lift rocket. Just over an hour after launch the rocket points the ATV in the direction of the ISS and gives it a boost to send it on its way, with journey time to the station after separation from the rocket taking about ten days. The ATV is multifunctional, meaning that it is a fully automatic vehicle that also possesses the necessary human safety requirements to be boarded by astronauts when attached to the ISS. Approximately 60 per cent of the entire volume of the ATV is made up of the integrated cargo carrier (ICC). This attaches to the service module, which propels and manoeuvres the vehicle. The ICC can transport 6.6 tons of dry and fluid cargo to the ISS, the former being pieces of equipment and personal effects and the latter being refuelling propellant and water for the station.

As well as taking supplies, ATVs also push the ISS into a higher orbit, as over time it is pulled towards Earth by atmospheric drag. To raise the ISS, an ATV uses about four tons of its own fuel over 10-45 days to slowly nudge the station higher.

The final role of an ATV is to act as a waste-disposal unit. When all the useful cargo has been taken off the vehicle, it is filled with superfluous matter from the ISS until no more can be squeezed in. At this point the ATV undocks from the station and is sent to burn up in the atmosphere.

ATV docking procedure



POST-LAUNCH

Release
After launch, the Ariane 5's main stage gives the ATV an additional boost to send it on its way to the ISS.

Tracking
The ATV uses a star tracker and GPS satellites to map its position relative to the stellar constellations and Earth so it can accurately locate the space station.

APPROACH

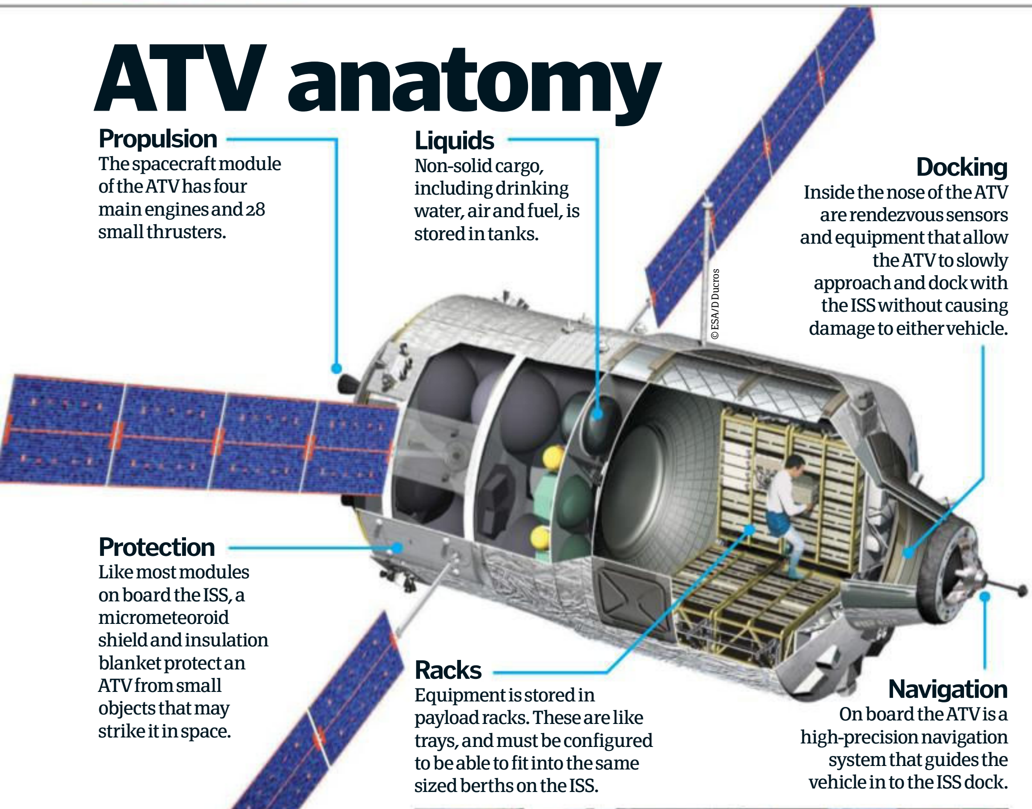
Locking on
When it's 300m (984ft) from the ISS, the ATV switches to a high-precision rendezvous sensor called the video meter to bring it in to dock.

THE STATS
HOW AN ATV MEASURES UP

LENGTH 10.7m (35.1ft) **DIAMETER** 4.5m (14.8ft) **SPAN** 22.3m (73.2ft)
VOLUME 48m³ (1,695ft³) **LAUNCH MASS** 20,700kg (45,636lb)

DID YOU KNOW? *The ESA hopes to upgrade the ATV into a human-carrying vehicle by 2020*

ATV anatomy



© ESA/D Ducros

Propulsion
The spacecraft module of the ATV has four main engines and 28 small thrusters.

Liquids
Non-solid cargo, including drinking water, air and fuel, is stored in tanks.

Docking
Inside the nose of the ATV are rendezvous sensors and equipment that allow the ATV to slowly approach and dock with the ISS without causing damage to either vehicle.

Protection
Like most modules on board the ISS, a micrometeoroid shield and insulation blanket protect an ATV from small objects that may strike it in space.

Racks
Equipment is stored in payload racks. These are like trays, and must be configured to be able to fit into the same sized berths on the ISS.

Navigation
On board the ATV is a high-precision navigation system that guides the vehicle in to the ISS dock.

Solar power
Four silicon-based solar arrays in an X shape provide the ATV with the power it needs to operate in space.

Currently, ESA ground control pilots the ATVs remotely

The MPLM was transported inside NASA's Space Shuttle

© NASA

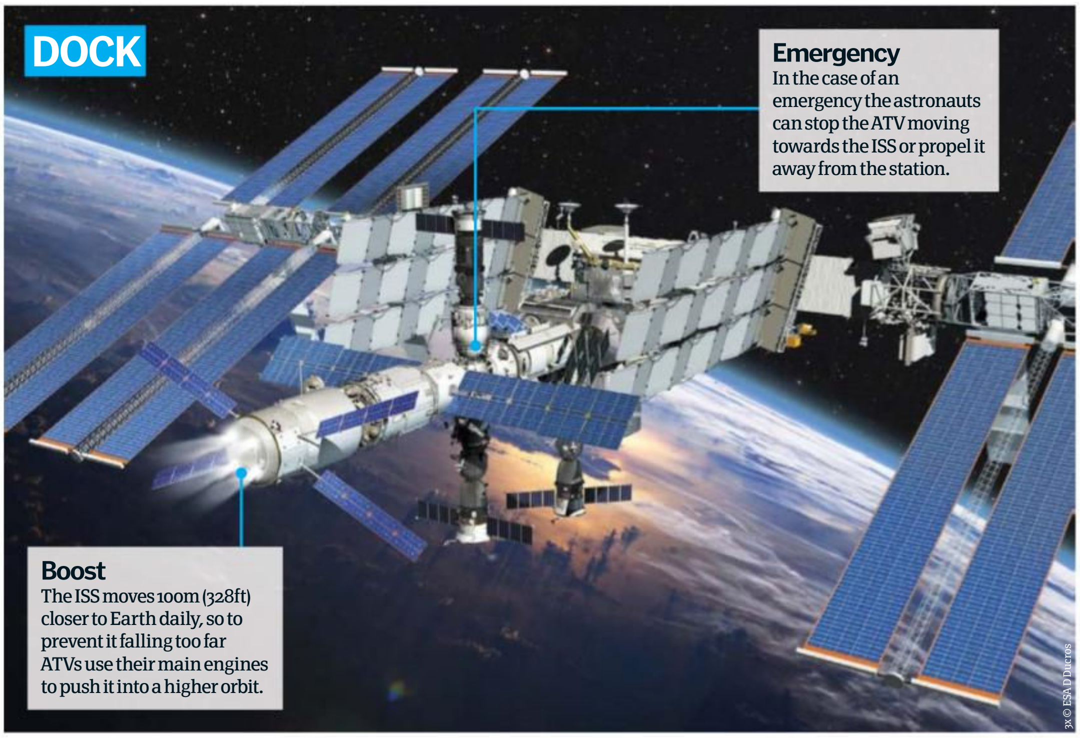
Other resupply vehicles

The ESA's automated transfer vehicle isn't the only spacecraft capable of taking supplies to the ISS. Since its launch, three other classes of spacecraft have been used to take cargo the 400 kilometres (250 miles) above Earth's surface to the station. The longest serving of these is Russia's Progress supply ship, which between 1978 and the present day has completed over 100 missions to Russia's Salyut 6, Salyut 7 and Mir space stations, as well as the ISS.

Succeeding Progress was the Italian-built multipurpose logistics module (MPLM), which was actually flown inside NASA's Space Shuttle and removed once the shuttle was docked to the space station. MPLMs were flown 12 times to the ISS, but one notable difference with the ATV is that they were brought back to Earth inside the Space Shuttle on every mission. The ATV and MPLM share some similaritie s, though, such as the pressurised cargo section, which is near identical on both vehicles.

The last and most recent resupply vehicle is the Japanese H-II transfer vehicle (HTV). It has completed one docking mission with the ISS to date, in late 2009, during which it spent 30 days attached to the station.

Lasers
Two laser beams are bounced off mirrors on the ISS so the ATV can measure its distance from the station, approaching at just a few centimetres a second.



DOCK

Emergency
In the case of an emergency the astronauts can stop the ATV moving towards the ISS or propel it away from the station.

Boost
The ISS moves 100m (328ft) closer to Earth daily, so to prevent it falling too far ATVs use their main engines to push it into a higher orbit.

3x © ESA D Ducros

> "Practical solar cells only became a reality thanks to the development of new semiconductors such as silicon"

Solar-powered spacecraft

Harnessing energy from the Sun, solar-powered space probes like Juno are taking environmentally friendly technology farther than ever before…

When you're launching a space probe to a distant planet, every kilogram counts. Every aspect of the design is a compromise between weight and scientific capability. With engine fuel at a premium, and batteries heavy and limited in life, solar cells – which draw their energy from the Sun itself – are an ideal way of generating power.

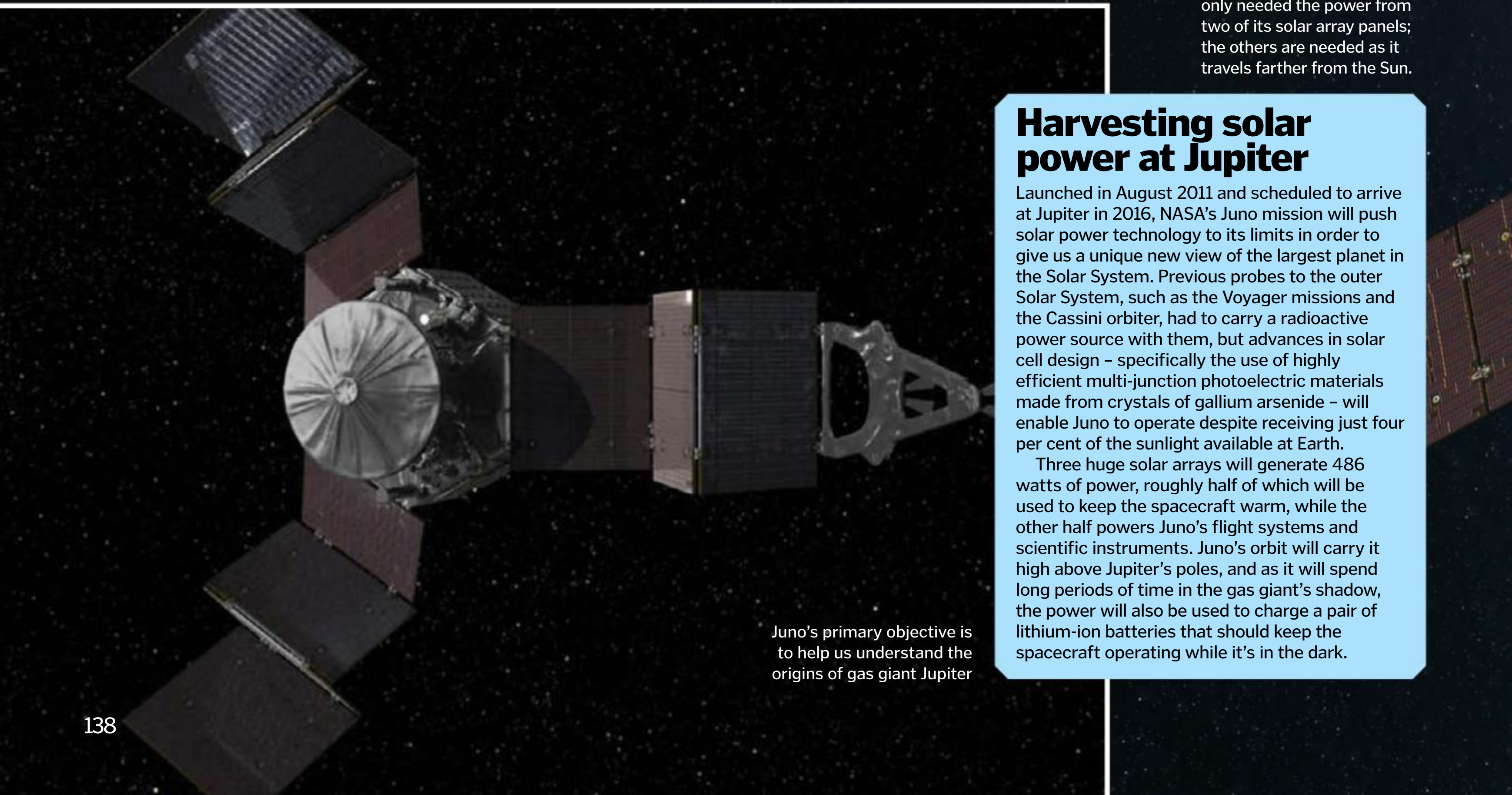
Solar cells rely on the photoelectric effect, which causes current to flow through certain materials when they are struck by light. The effect was discovered as early as the mid-1800s, and explained by Albert Einstein in 1905. It arises when individual photons of light striking a surface provide enough energy for charge-carrying subatomic electrons to break free of their individual atoms.

However, practical solar cells only became a reality thanks to the development of new semiconductor materials such as silicon and gallium arsenide in the mid-Fifties – just in time for them to be used in some of the earliest Earth satellites, and later in space probes.

For more far-flung missions, however, there's a stumbling block: the energy available from sunlight drops proportionally with distance from the star. As a result, solar energy has until recently only been a viable power source for missions to the inner Solar System (ie as far out as Mars). Advances in the efficiency of solar cells, along with the ability to pack and unfurl larger arrays (each carrying many separate cells) are starting to change that, as ably demonstrated by the Juno mission to Jupiter.

While most spacecraft still use solar cells purely for powering on-board systems, an increasing number are using them for propulsion too. Solar-electric, or 'ion engine', propulsion uses sunlight to split propellant into electrically charged ions and fire them out of the engine at extremely high speeds. The acceleration force this produces is tiny, but can be sustained for months or even years with just a small fuel supply. This makes it perfect for use on complex missions such as the Dawn probe currently touring the Asteroid Belt.

Coming online
Directly after launch, Juno only needed the power from two of its solar array panels; the others are needed as it travels farther from the Sun.



Juno's primary objective is to help us understand the origins of gas giant Jupiter

Harvesting solar power at Jupiter

Launched in August 2011 and scheduled to arrive at Jupiter in 2016, NASA's Juno mission will push solar power technology to its limits in order to give us a unique new view of the largest planet in the Solar System. Previous probes to the outer Solar System, such as the Voyager missions and the Cassini orbiter, had to carry a radioactive power source with them, but advances in solar cell design – specifically the use of highly efficient multi-junction photoelectric materials made from crystals of gallium arsenide – will enable Juno to operate despite receiving just four per cent of the sunlight available at Earth.

Three huge solar arrays will generate 486 watts of power, roughly half of which will be used to keep the spacecraft warm, while the other half powers Juno's flight systems and scientific instruments. Juno's orbit will carry it high above Jupiter's poles, and as it will spend long periods of time in the gas giant's shadow, the power will also be used to charge a pair of lithium-ion batteries that should keep the spacecraft operating while it's in the dark.

KEY DATES
SOLAR POWER

1958
The US launches Vanguard 1 (right), a grapefruit-sized satellite and the first to be powered by the Sun.

1970
The Soviet Union's Lunokhod 1 is the first solar-powered rover to land on the Moon.

1998
NASA's Deep Space 1 mission (right) pioneers solar-electric propulsion, paving the way for missions like the Dawn probe.

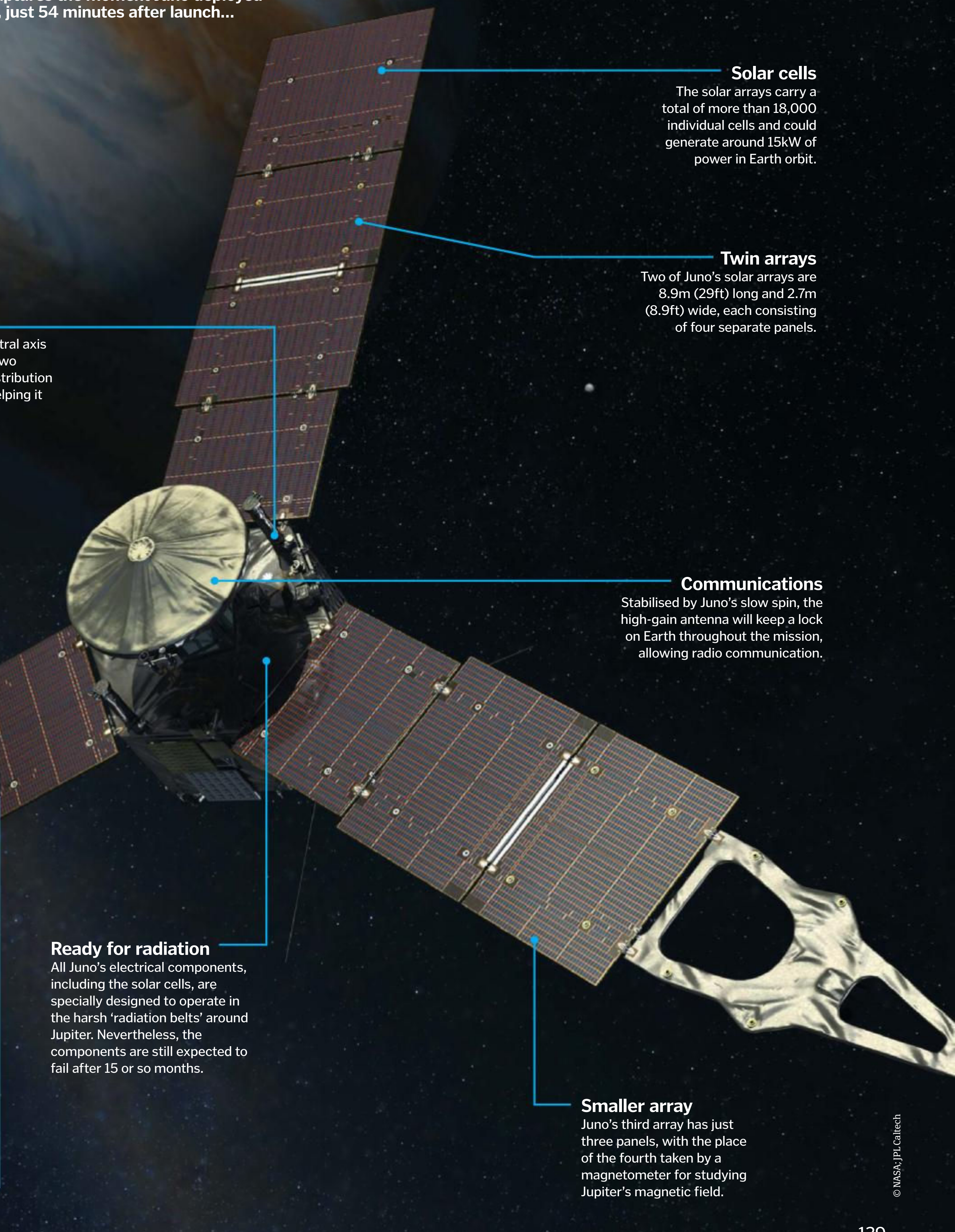
2010
JAXA's IKAROS spacecraft launches and successfully uses a solar sail as its main means of propulsion.

2011
Juno launches – the first spacecraft to use solar power in the outer Solar System.

DID YOU KNOW? *The solar cells on Vanguard 1 powered a transmitter that kept sending signals to Earth for almost seven years*

Unfurling Juno's wings

This artist's impression captures the moment Juno deployed its enormous solar arrays, just 54 minutes after launch...



Solar cells
The solar arrays carry a total of more than 18,000 individual cells and could generate around 15kW of power in Earth orbit.

Twin arrays
Two of Juno's solar arrays are 8.9m (29ft) long and 2.7m (8.9ft) wide, each consisting of four separate panels.

Rotation
Juno spins on its central axis roughly once every two minutes, with the distribution of the solar arrays helping it to remain stable.

Communications
Stabilised by Juno's slow spin, the high-gain antenna will keep a lock on Earth throughout the mission, allowing radio communication.

Ready for radiation
All Juno's electrical components, including the solar cells, are specially designed to operate in the harsh 'radiation belts' around Jupiter. Nevertheless, the components are still expected to fail after 15 or so months.

Smaller array
Juno's third array has just three panels, with the place of the fourth taken by a magnetometer for studying Jupiter's magnetic field.

The statistics...

Juno spacecraft

Launch: 5 August 2011

Launch mass: 3,625kg (7,992lb)

Scheduled Jupiter arrival: July 2016

Number of Jupiter orbits: 33

Planned orbit altitude: 5,000km (3,100mi)

Key instruments: UV imager/spectrometer; plasma detector; radio/plasma wave experiment; six-wavelength microwave radiometer

© NASA; JPL Caltech

Space planes

Discover how this new generation of aircraft will help us venture into space like never before…

Getting into space is no mean feat. Since the dawn of the Space Age we have relied on large, expensive and at times dangerous launch vehicles – namely rockets – to give payloads the necessary altitude and speed to get off our planet. Rockets use a huge amount of fuel, they're not reusable (hence their expense) and, perhaps most importantly, they have been known to fail with often disastrous consequences. But what if there was another way to travel off our world?

The holy grail of space exploration has long been to design some sort of vehicle that can launch from the ground, journey into space and return to Earth in one piece, with no expendable components and minimal risk. Space planes are one such idea that have been touted (and partially tested, as we'll explain later). They are vehicles that can take off from runways, travel into space and return to Earth. As their name would suggest they are essentially aeroplanes, but with a key difference: they are capable of operating both in the forgiving atmosphere of Earth and in the much harsher environment of space.

The first space plane of sorts was the rocket-powered X-15 jet in the Sixties. It remains the fastest manned vehicle ever launched and performed what is known as a suborbital flight, where a vehicle reaches the boundary of space and returns to Earth but does not enter orbit. Only two of the multitude of flights it performed technically reached space, but it lent weight to the concept of a space plane nonetheless.

Since then we have seen a few other pretenders take to the skies. NASA's Space Shuttle was a space plane in the sense that it glided back to Earth after completing operations in orbit, but as it launched on top of a rocket it was never regarded as a true space plane. The Soviet-built Buran spacecraft performed in much the same manner.

Now, in the coming years, we can expect to see more genuine space planes, each with a different design. The vehicle that has garnered the most attention in recent years has been

SpaceShipTwo

Virgin Galactic's eight-seater SpaceShipTwo space plane will take off from Virgin's own Spaceport America in New Mexico. It will be carried by a larger mothership – WhiteKnightTwo – before detaching in the upper atmosphere and using a rocket motor to propel itself into orbit. It will be used initially for space tourism, with 400 passengers already paid up, and will aim to begin flights in late-2015/early-2016.

★ THE PIONEER

Lynx Mk 1

Unlike SpaceShipTwo, California-based XCOR's Lynx space plane lifts off and lands all by itself. Carrying one pilot and just one paying passenger, it can take off from a conventional runway, taking a steep climb of about 75 degrees before levelling out into suborbit and then returning to Earth. It too will begin flights later in 2015 or at the beginning of 2016.

★ THE CONTENDER

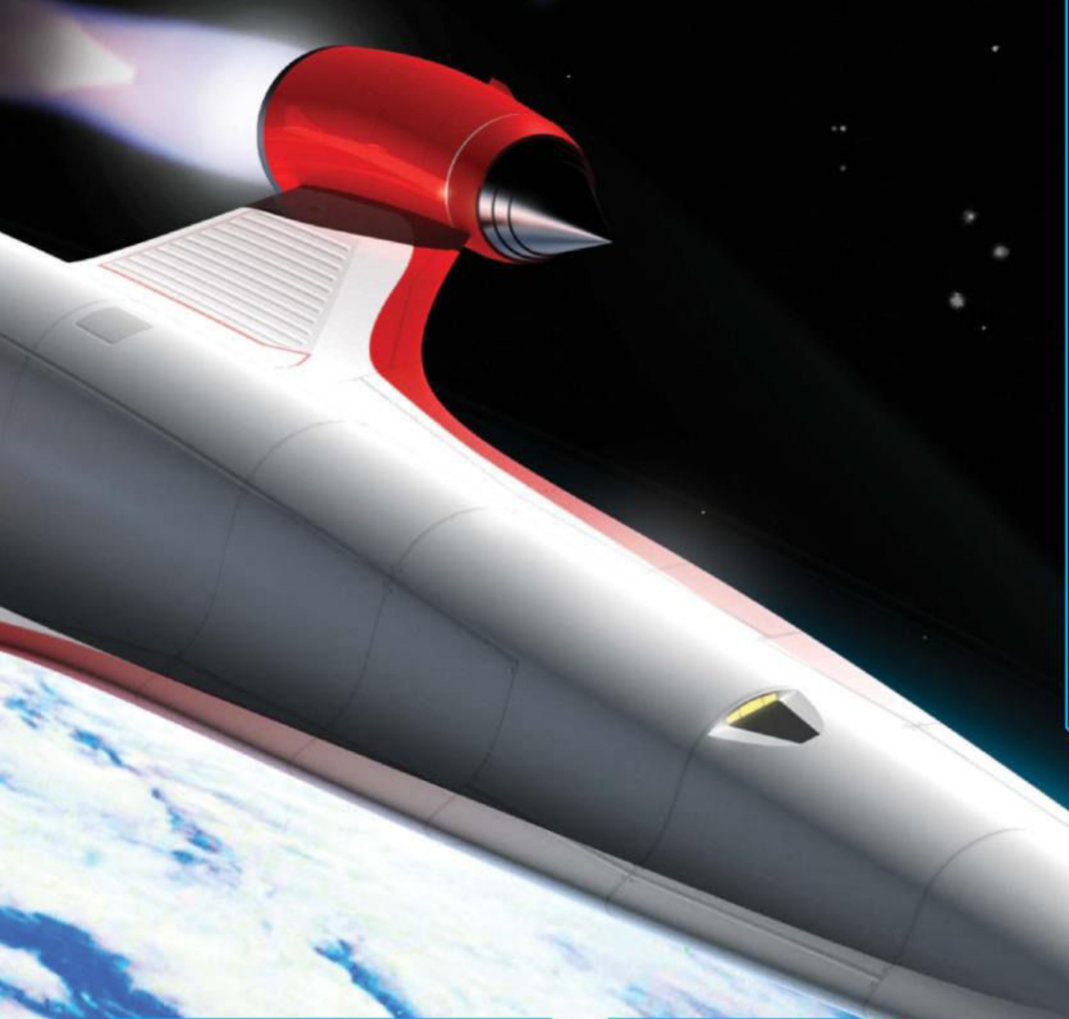
RECORD BREAKERS
PRIZE FLIGHT

$10MN

FIRST PRIVATE SPACEFLIGHT

In 2004, SpaceShipTwo's predecessor SpaceShipOne completed the first two-manned private spaceflights with pilots Brian Binnie and Mike Melvill, scooping the $10mn (£6.6mn) Ansari X Prize in the process.

DID YOU KNOW? *In the 1960s Pan Am opened registration for trips to the Moon in space planes, but they never materialised*



Spaceport vs airport

There are currently two major spaceports being built in the USA: the Mojave Air and Space Port in California and Spaceport America in New Mexico.

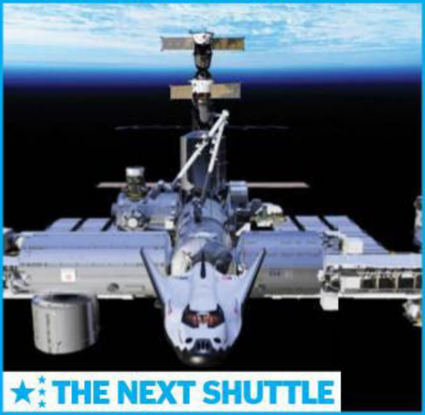
Spaceports must be able to support the added force associated with a space plane both at launch and landing. Thus, runways must be reinforced and also longer than conventional ones as space planes require a longer distance to accelerate and brake.

Spaceports also need training facilities to prepare their passengers for the rigours of spaceflight. Like rocket launch sites, spaceports benefit from being placed near the equator too. This allows the aircraft to get an added boost from the rotation of the Earth, making it slightly easier (and so less costly) to reach orbit than if they were launching farther away from the equator.

Spaceport America in New Mexico, USA, is where Virgin Galactic's SpaceShipTwo will be based

Dream Chaser

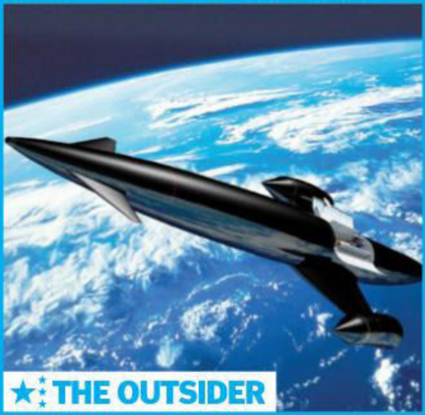
Sierra Nevada Corporation's Dream Chaser will launch on top of a rocket (probably an Atlas V) into orbit. It is expected to be able to dock with the ISS before gliding back to Earth, just like the Space Shuttle once did. It should make its maiden trip in 2015.



★ THE NEXT SHUTTLE

Skylon

UK-based Reaction Engines Limited's Skylon plane could be a game-changer. It's intended to launch from a reinforced runway and return to Earth in a single unit and could carry 24 passengers. Development is ongoing and it may well be flying before the decade is out.



★ THE OUTSIDER

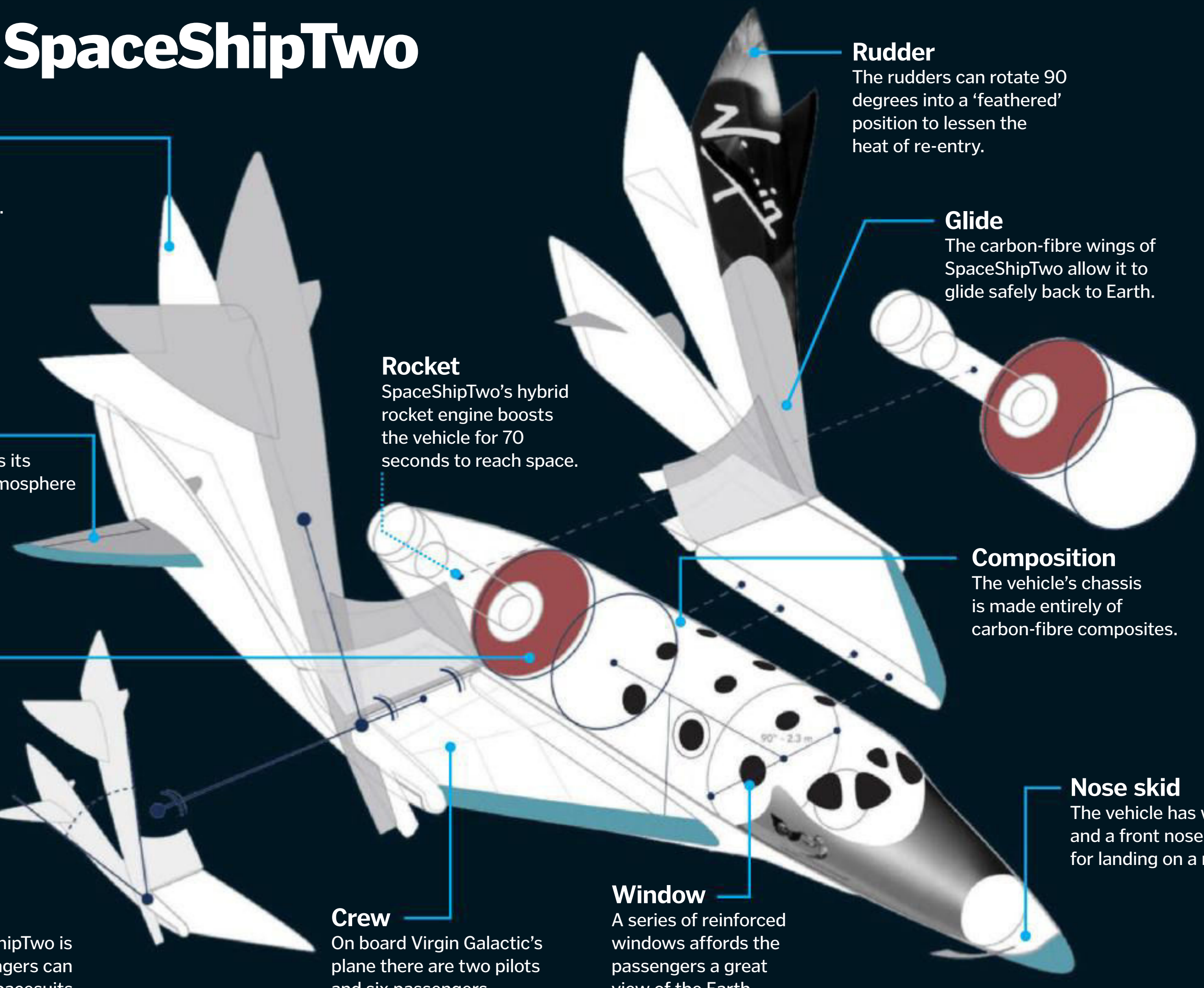
Virgin Galactic's SpaceShipTwo. This rocket-powered aeroplane is lifted into the sky by a larger mothership, WhiteKnightTwo, before separating and using its rocket engine to take six paying customers into space. Here, at a cost of $200,000 (£133,000) each – although this has recently risen to $250,000 (£166,000) – they experience six minutes of weightlessness.

It's not the only space plane in development though. A company called XCOR Aerospace has been quietly building its own vehicle, known as the Lynx aircraft, which will be able to take paying passengers into space. Unlike SpaceShipTwo it doesn't have a carrier vessel, and thus will be able to launch and land itself on a runway, bringing us a big step closer to the true vision of a space plane.

But aside from taking tourists on out-of-this-world trips, space planes have another more important use. It is expected, specifically with future versions of SpaceShipTwo and Lynx (eg SpaceShipThree and Lynx Mk 2), that they will eventually be able to launch payloads such as satellites into orbit. To do so they will reach their peak altitude before releasing a smaller spacecraft, which carries the payload into orbit. This would be a huge advancement for satellite operators, who at the moment must rely on rockets to get satellites off Earth but, in future, they could use aircraft at a much lower cost.

Space planes are also expected to fly passengers and crew not only into suborbit, but into full orbits around the Earth. One company hoping to do this is Sierra Nevada Corporation (SNC) with its Dream Chaser craft. With funding from NASA, they are hoping to launch this plane as the successor to the Space Shuttle. Travelling atop an Atlas V rocket, it will be capable of taking up to seven people into low Earth orbit

Inside SpaceShipTwo



Dimensions
SpaceShipTwo is 18m (60ft) long and has a wingspan of 8m (27ft).

Rudder
The rudders can rotate 90 degrees into a 'feathered' position to lessen the heat of re-entry.

Glide
The carbon-fibre wings of SpaceShipTwo allow it to glide safely back to Earth.

Rocket
SpaceShipTwo's hybrid rocket engine boosts the vehicle for 70 seconds to reach space.

Elevon
SpaceShipTwo controls its pitch and roll in the atmosphere with movable elevons.

Composition
The vehicle's chassis is made entirely of carbon-fibre composites.

Nose skid
The vehicle has wheels and a front nose 'skid' for landing on a runway.

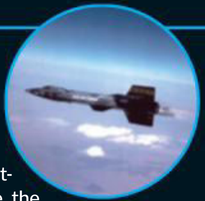
Cabin
The interior of SpaceShipTwo is pressurised, so passengers can enjoy space without spacesuits.

Crew
On board Virgin Galactic's plane there are two pilots and six passengers.

Window
A series of reinforced windows affords the passengers a great view of the Earth.

History of space planes

How It Works picks out a few key dates in the evolution of space-faring vehicles



1959
The first rocket-powered plane, the North American X-15, makes its maiden flight.

1963
Pilot Joseph Walker takes the X-15 into space, making it the world's first space plane.

1981
The Space Shuttle, capable of taking a crew and cargo to and from orbit, launches for the first time.

1988
The Soviet-built Buran space shuttle makes its first and only flight into space.

DID YOU KNOW? *Rolls-Royce and British Aerospace studied a space plane concept called HOTOL back in the Eighties*

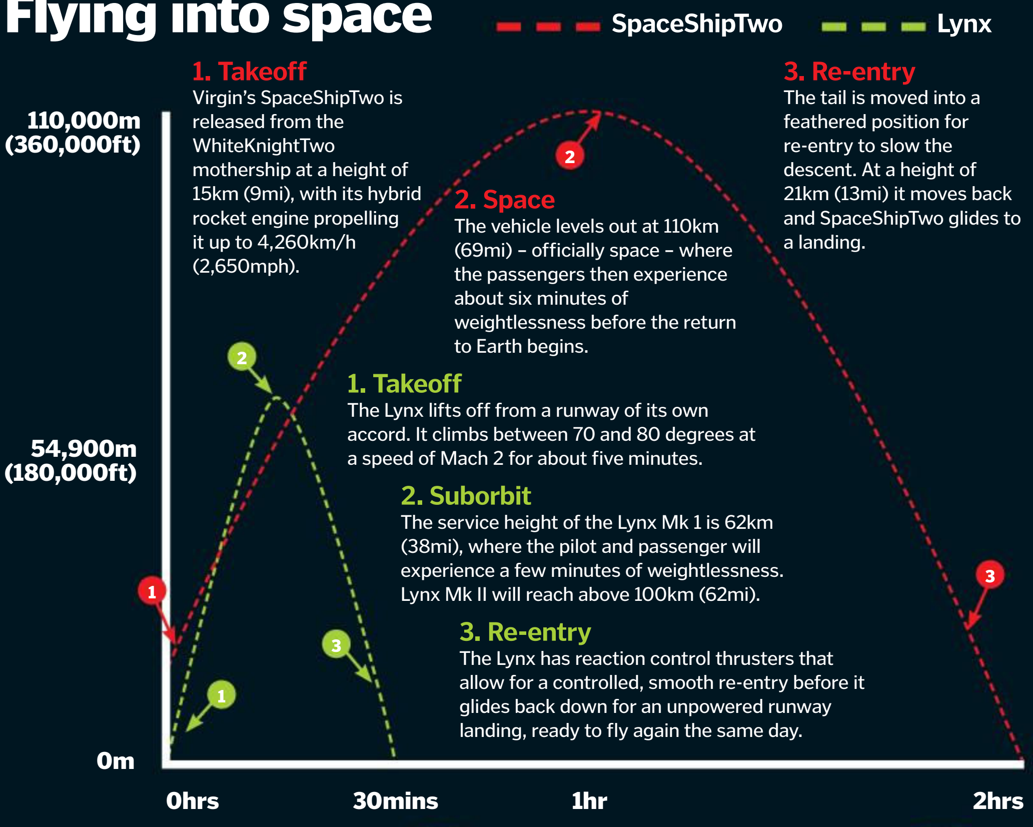
(LEO) where they could dock with the International Space Station (ISS). This would provide the ISS with another means of transporting crews to the station aside from Russia's Soyuz spacecraft. After leaving the ISS, the Dream Chaser will fly back down to Earth much like a regular aeroplane.

Another vehicle designed to take both people and cargo into orbit – but which is further behind in its development than the Dream Chaser – is the Skylon space plane. Currently being developed by UK-based Reaction Engines Limited (REL), Skylon could be a revolution in space travel if it ever flies, as it is larger than SpaceShipTwo and boasts a much bigger hold.

REL has stated that when Skylon lifts off – hopefully at some point towards the end of this decade – it will reduce the cost of taking a payload into space from £15,000 ($23,000) to just £650 ($990) per kilogram. It could also transport as many as 24 people off our planet at a time. The vehicle will use a hybrid air-breathing rocket engine to reach orbit in a single stage before gliding back to the surface.

The goal of space planes is, ultimately, to reduce the cost of going to space. While the early flights of SpaceShipTwo and Lynx will predominantly be centred around tourism, it is fully expected that space-faring aircraft will be used to take useful cargo into orbit in the not-too-distant future. Making space more accessible will enable us to operate more efficiently in Earth orbit, while the tourism aspect will help to fund those endeavours. Indeed, companies like Virgin Galactic have said that, while the first few hundred tourist flights will be quite expensive, future tickets should become much more affordable.

Flying into space



1. Takeoff
Virgin's SpaceShipTwo is released from the WhiteKnightTwo mothership at a height of 15km (9mi), with its hybrid rocket engine propelling it up to 4,260km/h (2,650mph).

2. Space
The vehicle levels out at 110km (69mi) – officially space – where the passengers then experience about six minutes of weightlessness before the return to Earth begins.

3. Re-entry
The tail is moved into a feathered position for re-entry to slow the descent. At a height of 21km (13mi) it moves back and SpaceShipTwo glides to a landing.

1. Takeoff
The Lynx lifts off from a runway of its own accord. It climbs between 70 and 80 degrees at a speed of Mach 2 for about five minutes.

2. Suborbit
The service height of the Lynx Mk 1 is 62km (38mi), where the pilot and passenger will experience a few minutes of weightlessness. Lynx Mk II will reach above 100km (62mi).

3. Re-entry
The Lynx has reaction control thrusters that allow for a controlled, smooth re-entry before it glides back down for an unpowered runway landing, ready to fly again the same day.

2004
Scaled Composites' space plane completes the first privately funded human spaceflight.

2005
Richard Branson's Virgin Galactic acquires Scaled Composites and then begins work on SpaceShipTwo.

2008
XCOR Aerospace announces that it will begin development of the Lynx space plane.

2013
SpaceShipTwo makes its first rocket-powered flight, a key step to full launches.

Steve Isakowitz

The Executive Vice President and Chief Technology Officer at Virgin Galactic tells us why we should be excited about space planes

Why are space planes important?
Space travel is one of the only transportation modes where we throw everything away every time we fly. What we're trying to achieve is the ability to fly these suborbital flights, bring down the [space plane], turn it around quickly and re-fly it over and over again.

Will tickets to space become cheaper?
That is our goal, to open up the space frontier for anybody who has the desire to go there. Once we prove this second-generation vehicle [SpaceShipOne was the first] we expect to have a third, fourth and fifth generation that will continue to drive down costs and improve reliability.

What differentiates SpaceShipTwo from the Lynx?
We're giving people the opportunity to unbuckle from their seats and have the opportunity to float within the cabin and experience both the euphoria of zero-g and looking out the windows and seeing an incredible view of Earth.

What can we expect in the future?
One of the things we keep our eyes on is point-to-point travel, the idea of flying between two very distant cities but at a fraction of the time that it takes a commercial airline to do it. You might be able to fly from Tokyo to Los Angeles in a third of the time that an airline currently does. That could be a huge industry that one could tap into [sometime in this decade] with some of the very technologies that we're trying to develop.

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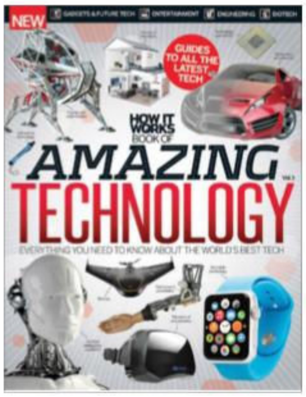

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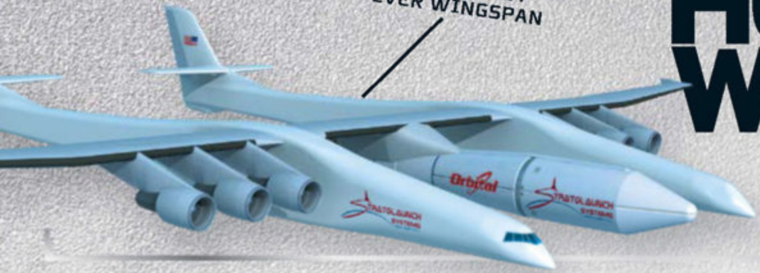
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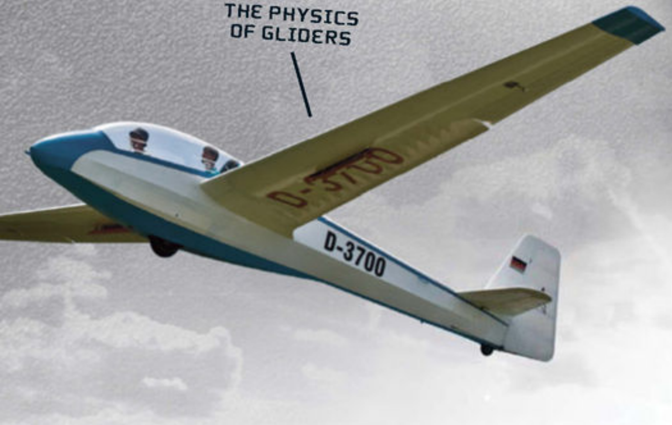
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